

# Institut de recherche pour le développement

TRAINING SCIENTISTS

SHARING KNOWLEDGE AND RESOURCES

FINDING APPLICATIONS

CONDUCTING RESEARCH



Institut de recherche  
pour le développement

# Conte

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around the world

# THE IRD around the world



0 100 200 km

0 100 200 miles

French Polynesia

Mexico

PG

China

Peru

Ecuador

Colombia

Marquesas

Guadeloupe

French Guiana

Senegal

Gambia

Guinea

Cote d'Ivoire

Sierra Leone

Liberia

Spain

France

Italy

Germany

Sweden

Norway

Denmark

Angola

South Africa

Kenya

Swaziland

Lesotho

Botswana

Malawi

Zambia

Mozambique

India

Thailand

Malaysia

Singapore

Indonesia

Philippines

Vietnam

La Réunion

Madagascar

Seychelles

Kenya

Swaziland

Lesotho

Botswana

Malawi

Zambia

Mozambique

India

Thailand

Malaysia

Singapore

Indonesia

Philippines

Vietnam

Laos

Myanmar

Burma

Cambodia

Sierra Leone

New Caledonia

Vanuatu

Samoa

Tonga

Fiji

Vanuatu

Samoa

Tonga

Fiji

Vanuatu

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Vanuatu

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Vanuatu

Samoa

Tonga

Fiji

Vanuatu



its two hubs in Bondy and Montpellier and actively preparing for the move to its new head office in Marseille. In the developing world, Africa and the Mediterranean region remain priorities. The new site policy prioritises a small number of major themes and helps to strengthen the Institute by opening up to other research players, universities and institutions, as witness the growing number of joint research units; these now account for 53% of our research units.

The number of articles published in top international journals has been growing for the past ten years and attests to the quality of the work done by IRD scientists. A breakdown of publications reflects the Institute's priority themes : emerging diseases, climate change, water resources, ecosystems, migration and poverty, all of which are now major global issues. The year's scientific results confirmed IRD's role as a major player in research for development. These included identification of the natural reservoir for Marburg disease in Africa, analysis of Patagonian ice cores to achieve a better understanding of past climates, research on climate phenomena in Africa and study of the impact of human activity on water resources in the Sahel.

Year by year, the IRD demonstrates its ability to adapt to a changing world, 2007 confirmed that ability yet again, with the implementation of some major operations and new directions that had been defined in the preceding years. The inter-establishment agency AIRD has been creating a fluid role for itself in the research landscape and in 2007 issued four calls for projects. In Metropolitan France, the Institute has been reorganising around

The IRD also places great importance on building the capacities of Southern research structures. It trains students and young researchers to consolidate their skills and works in partnership with these countries' top research teams. While the IRD has a distinctive identity and an undeniable ability to conduct research useful for development, it must now pursue two essential goals. It must adapt to the effects of globalisation on the development capabilities of Southern countries and share its knowledge effectively with its partners in France, in Europe and worldwide.

*evened*

Jean-François GIRARD  
Chairman

Michel LAURENT  
Director general

# /Editorial

# A new site policy

The master plan for the IRD's new site policy stemmed from a series of meetings held in the five regions of the world where the institute works, and from a precise inventory of its scientific and partnership strengths. The new policy aims to reshape the Institute's research arrangements in the light of its objectives, contact with the State, refocusing its potential and activities on the great development challenges of our day.

**Structuring, regional focus, partnership**  
The task is to identify and support a definite number of high-quality regional projects. First it within the IRD's priority themes. They must be conducted by multidisciplinary teams working from high-level platforms open to international participation.

Contributing to the construction of a European research space and promoting South-South partnerships have also been identified as priorities. Projects will therefore be supervised by limited partnerships involving Northern and Southern institutions. Projects must capacity aim to build scientific capacity and scientific communities in the South, and must take into account the level of development of these communities.

Further, as a strategic response to Southern countries' demand for training, the IRD must actively nurture partnerships with universities and make the conjunction of training and research an essential component of any project.

**Top priorities: Africa and the Mediterranean region**

The IRD's research arrangements abroad are heretofore organised under five major regions: West and Central Africa, East Africa, Southern

Africa and Indian Ocean, North Africa and Middle East, Latin America, Southeast Asia and Pacific. Although West and Central Africa is present take up half the Institute's energies, greater research investment is to be made in the countries on the southern and eastern shores of the Mediterranean. Developing regional dynamics among and between these countries has been identified as a priority.

**Fostering synergy, exchange and partnerships in France**

In France, the IRD's work will be managed from two major centres, in the north and south of the country. The northern centre will cover the establishments in Clermont, Orleans and Bondy and the southern centre will cover the research done in Montpellier, Sete, Grenoble, Perpignan, Toulouse, Nice, Marseille, Valfranche-sur-Mer and Clermont-Ferrand. The IRD will be strengthening its partnerships with universities, especially by creating joint research units and having IRD researchers play a greater part in teaching for doctoral and Master's degrees. It will also focus on increasing its teams' involvement in the new regional research structures that must concentrate human and technological resources from different institutions, to bring greater coherence to these structures.

**The overseas territories, a major asset for European outreach**

The French overseas territories are especially favourable places for French research with a view to consolidating European research for development. Here the IRD will function as intermediary and support service for decentralised research, mobilising the necessary resources and scientific potential to help its partners in these territories forge international relations in their geographical region. Here even more than in Metropolitan France it is important for the IRD to work more closely with the universities and local resources with them, particularly human resources. The IRD is committed to helping the French overseas territorial authorities in their cooperation policies and helping them make use of the available European funds. The Institute's responsibilities as an Agency add to these initiatives a structuring dimension in terms of regional policy on research for development.



# AIRD takes root in the research landscape

AIRD (Agence inter-établissement de la recherche pour le développement, "the Agency") is a joint body among French research institutes\*, whose function is to augment national and European research efforts in favour of development. It was set up by the IRD in 2005, at the behest of the French government. Since then AIRD has become an integral part of the research scene, working with researchers, authorising bodies in the North and beneficiaries in the South.

For its first full year in operation, AIRD applied an innovative concept: it mediated discussions about priorities in research for development, drew up a common programme and monitored this programme on a collegial basis. It had to persuade its member institutes to commit resources to the Agency, which is offered to them as a tool for their work. The Agency also demonstrated its ability to organise calls for projects in broad collaboration with a large number of parties.

AIRD's steering committee is a collegial body that includes Southern partners and representatives of French universities and research institutes. Over the year, it identified the main priority themes for the common programme: Governance and public policy; Health; Food security; nutrition and agricultural and aquacultural production; Impact of climate change and societies; adaptation. New and traditional energy sources. On this basis the steering committee validated calls for proposals and research programmes, whose management is entrusted to the Agency. It also initiated new projects in these priority fields.

AIRD's coordinating committee has a more executive function. It is the body through which the Agency's funding institutions coordinate to facilitate research and the pooling of funds and to manage calls for proposals. Guidelines defining the missions and commitments of the Agency are currently being drawn up.

In 2006 the groundwork was laid for collaboration between AIRD and the Hewlett Foundation in the USA, to jointly fund a call for projects on the subject of population and development.

The following calls for proposals were issued, funded either by AIRD alone or jointly with other institutions:

- **ESF Riplesca.** The Ministry for Foreign Affairs appointed AIRD as operator for this programme on the original topic of how societies and ecosystems in West and Central Africa are adapting to the consequences of climate change. Ten African teams were selected for "target" projects and some twenty others for interdisciplinary projects.

- **Bird flu project.** This project is based on pooled funds from all the Agency's founding institutions. The funds are used to finance original research on the bird flu pandemic involving teams from North and South. The five partners in the project are CIRAD, the CNRS, INSEPIA, Institut Pasteur and the IRD.

- **The Souffles today.** The AIRD's participation in the call for proposals by the National Research Agency (ANR) is intended specifically to finance Southern teams selected along with their Northern partners for projects in the social and human sciences.

- **Biodiversity, Indian Ocean, Madagascar.** This call for proposals is being managed by the French Biodiversity Institute (IFB) and the CNRS. Its purpose is to encourage researchers in French laboratories to form partnerships with researchers in laboratories in Madagascar and the islands of the Indian Ocean, for projects connected with biodiversity conservation.

At present, AIRD may help to fund these projects in a variety of ways: it may pay operating credits or salaries, for example. Project activities and the use of the funds are rigorously tracked.

to start the Agency's activities and give it some scope for action, the IRD allocated €3.1 million under the heading of internal reorganisation. This made it possible to mobilise commitments from external sources for research programmes for development, amounting to nearly €10 million over several years.

\*The founding members of AIRD are CIRAD, CNRS, IFB, INSEPIA, Institut Pasteur and IRD.



Contact: aird@ird.fr



Protection against bird flu in Cameroon.

# The IRD in a nutshell

## Research for development

Founded in 1944, the Institut de Recherche pour le Développement is a French public research institute working exclusively for the development of Southern countries. It operates under the joint authority of the French Ministry responsible for research and for overseas development.

Its work focuses on the relationship between humans and their environment and, more particularly, on major priority issues – poverty reduction, international migration, emerging infectious diseases, climate change, water resources, ecosystems and natural resources.

## In France and abroad

Over 800 researchers and 1,000 engineers and technicians take part in major research programmes aimed at achieving sustainable development. As well as its head office, the IRD has two centers in metropolitan France and five in the French overseas territories. It has bases in 22 other countries in Africa, the Mediterranean basin, Asia, the Indian Ocean, Latin America and the Pacific. All in all it operates in some fifty countries.

\* Non-aid/Eurêka base.

## Partnership

IRD research is conducted in partnership with Southern institutions under French, European and international programmes. It provides training and network facilitation to build the capacities of Southern scientific communities and enable them to play a full part in the international scientific community. It also has a role in transferring knowledge to economic and social actors in the South and finding applications for research results, always with a mind to the interests of partner countries.

## Mobilising the scientific community for the

Southern countries  
Through ARIIO, the new inter-establishment agency for research for development for which it is responsible, the IRD has the task of mobilising French and European universities and major research bodies on research issues connected with development.

Engineers and technicians: two differentiating components in staff categories in the French civil service

## Key figures of

• €220  
million budget

€180 million in  
government grants

€21 million own resources  
71% allocated to staff pay

• 2,235  
staff

including

830 researchers

1,021 engineers and technicians

384 permanent local staff

• 929 (42% of total)

staff working outside Metropolitan France

Of whom

51% work in Africa

125 are on long-term missions

• 72

research and service  
units

including

38 joint units with  
other French research  
bodies or universities



## CELEBRATING LANDMARKS

In 2007 the IAD celebrated the 20th anniversary of its Montpellier centre, 40 years of cooperation with Peru and 50 years of cooperation with Tunisia

## RISKS



**Sensationalism mission**  
assesses geological risk in the Lesser Antilles and  
Study of the Pisco earthquake of 15 August 2007,  
Peru

## WATER



**Results of the Expert**  
group review on the future of the Niger River  
delivered

## LIVING RESOURCES

**Newly discovered plant bacteria symbiosis**  
mechanism holds promise for agriculture  
Coral  
lost play host to an unsuspected diversity of parasites  
IAD becomes a founding member of the Fondation  
Biodiversité IAD mobilises for the second  
International Rhizosphere conference in Montpellier

## CLIMATE

**First ice core**  
drilled on the San Valentin glacier  
in Chilean Patagonia  
AMM oceanographic  
survey on the African monsoon  
New light  
shed on the variability of the El Niño climate  
phenomenon

## MIGRATIONS

**Rapid population**  
growth, with the mass migration movements it brings, is  
a major handicap for development in most countries of  
sub-Saharan Africa

# 2007

• 1,000

scientific publications  
(excl. human/social sciences)

i.e.

1.7 publications per  
researcher per year

43%

jointly authored with Southern  
partners

• 6,500

hours of teaching  
by IAD researchers  
and engineers

55% in France

45% abroad

• 138

theses supervised  
including

83 submitted by

Southern researchers

• 195

grants awarded to  
Southern scientists



# RESEARCH for the south





# Natural hazards and climate

## Understanding to adapt to climate change

Global warming is now an undeniable fact. It is largely the result of human activity, and particularly of the increasing quantities of greenhouse gases released into the atmosphere. Its repercussions will be the most severe for populations in the South, who are particularly vulnerable and dependent on their environments. It is becoming urgent not only to reduce greenhouse gas emissions but also to apply strategies enabling populations to adapt and cope with climate change.

By enhancing knowledge, research plays a front line role in risk management and in making populations less vulnerable. IRD research in this field is based on the United Nations recommendations on climate change. Its aim is to observe and analyse ever more closely the climate changes of today and of past eras and to study their impact on the planet. Particular emphasis is laid on the future of water resources, animal and plant species, tropical ecosystems (forests, coral reefs, lakes and lagoons, deserts etc.) and population health.

## Prevention and management of natural and environmental hazards

Earthquakes, volcanic eruptions, landslides, tsunamis and floods: such are the natural hazards facing the people and environments of Southern countries. These are disasters that recur, sometimes seemingly at random, and are expected to become more intense in future. Then there are the risks incurred by human activity, such as atmospheric and environmental pollution. To reduce the impact of human activities, the IRD is conducting research into the processes that underlie such hazards. The researchers are involved in setting up and running observation and early warning networks and educating the populations concerned. IRD research concentrates on severe seismic events and their associated local impacts, the eruptive dynamics of volcanoes close to large towns, the potential impact of climate change and the mechanisms that cause desertification.

53 researchers

€9.54 million

# Seismic cycle and eruptive dynamics in the Vanuatu arc

The islands of the Vanuatu arc stand on a convergent zone where tectonic plates meet and seismic and volcanic activity is high. The region has been a focus of attention from earth scientists for many years. Now a new multidisciplinary research project is under way to improve understanding of the mechanisms responsible for major geological disasters.

What are the mechanisms that trigger volcanic eruptions and powerful earthquakes along convergence zones between lithospheric plates? Can we identify signals that will give advance warning of such disasters? The multidisciplinary programme Arc-Vanuatu is addressing these questions by concentrating on the Vanuatu subduction zone, a region where much pioneering work on plate tectonics has been done.

The plates in this zone are occasionally mobile. They are converging at a rate of 10 to 17 cm a year, and vertical movements can be as much as 1 cm. Earthquakes are frequent, with a quake of 7 or above occurring once a year on average. Eruption plumes rise almost constantly from

active volcanoes. All this makes conditions in the Vanuatu arc particularly favourable for observation and quantification to add to the world's understanding of geological hazards. In addition, the report's oral formulations are a remarkable tool for dating past events and building up a chronology of seismic cycles.

Over the past few years, research has mainly focused on volcanic gases and the islands' vertical movements. From measurements taken in the volcano plumes the scientists have estimated that in times of intense gas release the Anitym volcano spews out 20,000 tonnes of sulphur dioxide (SO<sub>2</sub>) a day, making it one of the biggest sources of SO<sub>2</sub> emissions on Earth. The average output of SO<sub>2</sub> from the archipelago's four main active volcanoes accounts for between 10% and 20% of emissions from all the volcanoes on the planet.

Geodetic measurements taken over the past ten years have now produced a precise measure of the horizontal movements between blocks and, for the first time, an estimation of the current vertical movements of the islands. From this data they have been able to model

the accumulation of stresses and the geometry of potential future seismic rupture zones.

The scientists on the Arc-Vanuatu programme are now studying the seismic cycle and complex dynamics, looking for warning signs that precede eruptions and strong quakes. The geophysical, geochemical and geological surveys that began in 2007 will continue until 2009 on the islands in the central part of the arc and the active volcanoes Anitym and Upoué as well as, to a lesser, another very active volcano, in the southern part of the arc. The work is mainly funded by the French national programme on tsunamis and telluric disasters. This is a multidisciplinary programme funded by ANR and involving the IRD, CNRS, IFREMER, CEA, French universities and the Vanuatu Land Department and Department of Geology, Mining and Water Resources.

Contact: [bernard.jellett@ird.fr](mailto:bernard.jellett@ird.fr)  
Publication: *Geophysical Research Letters* (2007)

+ Lapérouse/Vanuatu

+ Taking seismic measurements/Vanuatu



+ Vanuatu subduction zone

THE PARTNER

One of the Department's tasks is to monitor the volcanoes and assess seismic risk. It has a tradition of cooperation with the IRD going back to the 1970s. The collaboration currently includes training technicians, managers and also installing, maintaining and monitoring the many field stations on the archipelago's northern islands. There is a Vanuatu post-doctoral researcher on the staff of the ANR-funded programme. This joint action will bring the people of Vanuatu the benefits of natural hazard prevention and the scientific progress made in this field.

## Reading the climate record on Monte San Valentín, Chile

By reconstructing how Earth's climate has varied in the past, at different scales of space and time, climatologists are learning about the climate interactions between different parts of the world. This will improve their estimates of the consequences of climate change on local conditions – a particular challenge for Latin America, most of whose water resources are provided by shrinking glaciers in the Andes, from Ecuador to Patagonia. IRD teams and their partners climbed the redoubtable Monte San Valentín, the highest peak in Patagonia, to drill ice cores that hold traces of past climate change.

The glaciers of the Andes have been shrinking fast for several decades. It is they that provide most of the water resources for many South American countries. Change in the South American climate will thus directly affect water resources, a crucial issue that gives climatologists an urgent reason to find out how global climate change affects local climate.

To explore the mechanisms of today's climate system it is important to find out about past changes. IRD scientists working on the Andean glaciers extract ice cores, which hold a remarkable record of past climates. From the information on past climate variations gleaned from the cores, they can deduce how the local climate functions in relation to changes in the global climate.

While scientists have drilled numerous ice cores in the Antarctic and the IRD and their partners have drilled many in the tropical Andean glaciers, there was a missing link in the chain of cores stretching from the tropics to the South Pole, and that was Patagonia. The mission to the summit of Monte San Valentín, the highest peak in Chile, has just filled the gap, taking several ice cores including a 122 metre core right through the glacier to the rock beneath. It was a delicate operation requiring a site that offered satisfactory ice conditions for the climatologists, and acceptable working conditions. Even so, the team had to get used to working in winds of over 120 km/hour.

Four French laboratories and research units are involved in the programme as well as the Centre for Scientific Studies (CIES) in Valdivia. Chile. The longest ice core is currently being analysed and should provide a record for the past several thousand years. Its scope composition shows that this is high quality ice – it will be possible to interpret the measurements in terms of climate variations right down to seasonal changes for the most recent centuries. The next two years will be spent measuring the cores' isotopes, chemical makeup, gas content and radiogenic isotopes and integrating the results.

Contact: [bernard.pouyaud@ird.fr](mailto:bernard.pouyaud@ird.fr) [francisco.vincent@ird.fr](mailto:francisco.vincent@ird.fr)  
Publication: *Journal of Biophysical Research*

+ Camp on San Valentín/Chile

+ Ice core



THE PARTNER

Gino Casassa's CIES team in Valdivia works on glaciology and climate change. These scientists are experts on the glaciers of the Andes, Patagonia and Antarctica, analysing how these glaciers have responded to climate change in the past. They also investigate the biology of the ice, including the presence of algae, to study conditions for life in extreme environments. This is a particularly enriching partnership for both IRD and CIES teams because their respective areas of expertise and know-how complement each other very well. This not only produces very high quality research, it also enables each team to learn from the other and benefit from their expertise in particular fields. In a forthcoming exchange of good practices, the IRD will train Chilean researchers to study the pollen grains frozen into glaciers.

The many ecosystems of the intertropical belt – deserts, rainforests, major rivers, oceans, savannah, mountains – are home to the greater part of the world's biodiversity. Over-exploitation of their resources (intensive fishing, for example), deforestation for the timber trade or for farming, cultivation of highly vulnerable marginal land, ill-controlled urbanisation and climate change are all factors that threaten this biodiversity. It is essential to think about the importance and heritage value of biodiversity so as to manage it sustainably.

IRD researchers, along with their partners from North and South, are cataloguing this biodiversity. They study the organisation and complex functioning of tropical ecosystems on land, in fresh water and at sea.

To enable Southern researchers to rapidly appropriate the methods developed for data acquisition and sustainable management of their environment, the IRD offers them useful technologies ranging from modelling and remote sensing tools to simple oceanography equipment, marine acoustics technology and physical-chemical analysis laboratories adapted to local conditions. The research is of immediate relevance to local practices and policies faced with the challenge of sustainable development. The IRD is also looking at the physical-chemical properties of nanoparticles present in past and present environments (soil and latente, forest fires, lagoons etc.), by observation and experiment.

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# Sustainable management of Southern ecosystems

**143** researchers

€22.32

million

**226**

scientific publications

## Geodynamics of mineral resources in West Africa

Mineral resources account for more than 50% of exports from the 19 West African countries involved in the Agence programme. They play a crucial role in the region's development. The IRD and its partners are working to improve understanding of the geological structure and geodynamics of the West African shield in order to help countries with mineral wealth to manage these non-renewable resources sustainably. A further aim is to develop competency hubs for geoscience in these countries.

The West African shield, which constitutes the bedrock across large parts of West Africa, is an ancient rock formation dating from the Archaean era 2.5 billion years ago. Its rocks contain many precious minerals including gold and diamonds. The African Union recommends "expanding geoscientific research to enhance the exploration of the mineral wealth of the African continent" and cannot but welcome the Agence programme. Joining the IRD, BRGM and the universities of

Ouagadougou in Burkina Faso and Witwatersrand in South Africa, the programme is backed by the AfriMin mining consortium: several other international mining companies and the French government. It combines research, development and training for sustainable management of mineral resources in the West African shield.

The research includes a study of the geodynamic evolution of the shield and investigation of its little-known deep layers in order to guide future prospecting for metals and minerals. Young African researchers are involved in the work and an online undergraduate course will be made available to all on the Internet. A major challenge for the programme is to acquire geological, geophysical and petrological data in the field and combine these with existing data, much of which is scattered around different countries. All the data are being incorporated in a geographical information system that at present contains 1.50 Gb of geological and geographical data on West Africa and is available to the partners.

The information gathered and the very high resolution thermodynamic modelling investigations are already revolutionising the way the West African shield's geodynamic and thermal evolution is understood. This will greatly improve understanding of the geological processes at work at the time the mineral resources were laid down. And that in turn is an undeniable advantage for managing these non-renewable resources in future.

Contact: mark.jessell@ird.fr



THE PARTNER

Founded in 1974, the University of Ouagadougou was Burkina Faso's first higher education establishment. Today it has some thirty research laboratories in seven teaching units with subjects ranging from the human sciences to the exact sciences and including art and health.

The purpose of the university's close partnership with the IRD is to increase its research potential in the earth sciences. It has recently received funding from the IRD-coordinated Agence inter-établissements de la recherche pour le développement to set up a magnetism laboratory and build up a collection of rocks specific to the West African shield. The development of local expertise hubs is essential for enhancing geoscience training and research capacity in West African countries. These hubs will be able to advise policy making bodies and provide international mining companies with the competencies needed to exploit these resources.



## \Papua: exploring biodiversity in order to conserve it

Papua, sometimes called Asia's garden of Eden, may be the richest part of the world in terms of biodiversity. But there are delimitation programmes for the province and its biological resources are being heavily exploited. The first step towards protecting species is to identify and characterise them; a second step is to highlight their economic value and study how to exploit it sustainably. IRD scientists are exploring the diversity of rainbow fish in Papua with a view to domestication, aquaculture and conservation.

West Papua, Asia's last unspoiled Eden, is said to shelter more than half the recorded extent species of the Indo-Malaysian archipelago in widely diverse ecosystems that have yet to be explored. While delimitation on the Indonesian Islands is driving many species to extinction the IRD, in partnership with Indonesian Agency for Marine and Fisheries Research, is exploring the diversity of freshwater fish in order to preserve it. They

not only identify the species but also aim to select those that are of economic interest and can be domesticated for commercial production. Until 2004 the IRD's research focused on Bombo and Sumatra, where they identified and described 13 new species of fish and revealed some complex and usually ancient diversification processes. The recent research in Papua concerns rainbow fish, one of the most diverse fish groups in the region with 37 different species identified so far.

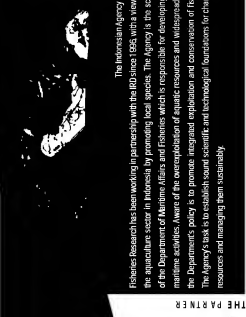
After catching specimens of some fifteen clearly different species the researchers consider nearly half of them to be new to science. While their main goal is to identify, describe and catalogue the species in terms of their evolution, conservation genetics and the systematics, they are also considering the potential economic uses of this diversity. Domesticating some species, especially the endangered ones, could help to conserve them as they could then be bred for the ornamental fish trade.

Some rainbow fish species that are caught in the wild for the ornamental fish market are already endangered due to overfishing. For Indonesia the IRD's research is of value in three respects: for exploring as yet unknown biodiversity, for investigating the possibilities for sustainable economic use of the resource, and for ensuring its conservation.

Contacts: Laurent Pouyaud [laurent.pouyaud@ird.fr](mailto:laurent.pouyaud@ird.fr)  
Jacques Skelton [skelton@ird.fr](mailto:skelton@ird.fr)  
Publication: *Odyssée*, Revue Internationale d'Ichthyologie

+ Rainbow fish Papua.

+ Exploring the fauna near Papua.



THE PARTNER

The Indonesian Agency for Marine and Fisheries Research has been working in partnership with the IRD since 1995, with a view to diversifying the aquaculture sector in Indonesia by promoting local species. The Agency is the scientific branch of the Department of Maritime Affairs and Fisheries which is responsible for developing the country's maritime activities. Aware of the overexploitation of aquatic resources and widespread illegal fishing, the Department's policy is to promote integrated exploitation and conservation of fish populations. The Agency's task is to establish sound scientific and technological foundations for characterising fish resources and managing them sustainably.



— A well Niger

# Water resources and access to water

**Integrated management of water resources**  
Providing clean drinking water in Southern countries is one of the great challenges of the 21st century. Even today there are a billion people in the world with no access to clean water and two and a half billion with no sanitation. This situation could worsen in the near future as the world population's water requirements continue to increase. Locating water resources, making them accessible to the people who need them while making sure they are managed sustainably – these are crucial keys to development. With integrated resource management based on sound knowledge of the water cycle it is possible to meet the vital need for access to water at every scale from village to region to river basin. This is the focus of IRD research in this field.

## **Sustainable development of coastal environments**

The aquatic environments studied include freshwater systems, coral reefs and coastal systems such as estuaries, lagoons and mangrove forests. To protect and use them sustainably it is essential to understand how they function and how they and their resources are affected by human activity. IRD research also addresses the need to reduce the impact of the increasingly serious degradation caused by water extraction, pollution etc. Another research area is fish biology and population dynamics – an essential basis for developing balanced, integrated aquaculture.

## Forecasting water resources in the Sahel for 2050?

The Sahel is particularly vulnerable to climate change, and recent changes in its surface water levels have not been the simple, direct result of rainfall trends. Human activity and climate change have a significant impact on the dynamics of surface runoff from the land into streams and lakes. The IRD and its partners have therefore taken those factors into account in developing hydrological models of the Beni basin. The Beni is the main tributary of the River Niger. The aim is to make projections for 2050 under a variety of different climatic and socio-economic scenarios.

While surface runoff obviously partly depends on the volume of rainfall, other factors are also involved: the physical properties of the soil, its plant cover and land use. In the Sahel, rainfall declined by about 20% in the 1970s and 1980s, but there does not seem to have been a corresponding decline in surface runoff. Human activity, and use and the influence of climate change have been having a significant influence on the hydrological responses of catchments and the dynamics of water

resources. For Sahelian regions where the capacity to adapt to climate change is low, these considerations must be taken into account in forecasting change and anticipating the hydrological future, to ensure that the population's future water requirements are met.

A vast forecasting programme to predict these trends to 2050 has been launched. It involves the IRD in partnership with various joint research units of CIRAD, Cersagat, the CNRS and Ingep, plus several French universities and higher education establishments and African partners including Bamako University, the Bamako National Engineering School and the Malian national hydrological and meteorological authorities. Using satellite imagery, socio-economic and demographic models, global and regional climate models and hydrological models, the scientists are analysing current and past situations to achieve a better understanding of the Sahel's climatic vulnerability since 1970.

Despite the difficulty of comparing aerial photographs and satellite images that are not homogeneous, it is clear from the first results that the region's plant cover has greatly changed over the period. The

proportion of woodland and eroded areas with little vegetation has greatly increased, to the detriment of wooded areas.

Analyses have yet to be done to characterise these past and present trends more precisely. After that the researchers draw up climatic and socio-economic scenarios to forecast probable trends in land surface states, their impact on water resources and hence the vulnerability of the environment in 2050. Understanding the impact of climate trends and human pressure on the hydrological future of the Sahel is not only a topical scientific question, it is an issue of major import for a region that is particularly vulnerable to climate change.

Contacts: Jean-annuaire.paturel@ird.fr  
jeanannuaire.paturel@univ-montp2.fr  
Publications: International Journal of Remote Sensing  
Proceedings of the Water Down Under 2008 conference

• Niger River delta.

• Satellite view of the Niger River delta, Mali.



THE PARTNER

The LOE, in the Earth Sciences department at the University of Bamako, studies natural water resources and their interactions with ecosystems and the environment, with a view to establishing sustainable management. Vulnerable groundwater bodies, spatial hydrological analyses, the impact of climate change, integrated water resource management, soil vulnerability and erosion – all these subjects are addressed in order to take account of the many dimensions concerned and develop an effective water resource management programme. Ongoing work concerns erosion in the upper Niger basin and the transfer of active matter in soil and water in the Sudanian zone in Mali (GAMM- Impact project) and the consequences of climate variability and increasingly intensive farming on groundwater and surface water resources in the Beni basin (RPEC-SA project).

## Revising the model of trophic cascades in tropical lakes

Shallow tropical lakes supply a majority of the water resources for people in the South, but algal and bacterial blooms frequently spoil the water's quality and jeopardise its use. Because the ecological models developed for temperate lakes cannot be directly transposed to tropical situations, the IRD is studying a number of processes in greater depth, to improve forecasting of the environmental consequences of human activities and global changes. The aim is to propose alternative rehabilitation and management methods using innovative environmental engineering methods.

Shallow tropical lakes are subject to wide hydroclimatic variations and are under severe human pressure. This makes them particularly subject to algal and bacterial blooms. Nitrates and phosphates from farmland washed into these lakes cause sudden proliferation of microscopic algae (phytoplankton) or cyanobacteria. The ecological functioning of the lake is affected and water quality deteriorates until it is unfit for human consumption and has to be purified before it can be drunk – a difficult and costly process. To improve understanding of the mechanisms at

work in these lake ecosystems and find solutions to the problem, the IRD is investigating the relations between fish, zooplankton, phytoplankton and nutrient flows.

Fish play a major role in the functioning of lakes by controlling the populations of macroorganisms. Although in temperate environments there is a linear trophic chain of prey and predator species from phytoplankton to zooplankton to fish, in the tropics there is a more complex trophic network. Omnivorous fish feed on both animal plankton and plant plankton (predominant), and the small herbivorous zooplankton does not control phytoplankton growth very efficiently. This complexity is increased by the process of nitrogen and phosphorus recycling. Low nitrogen levels, which are typical of tropical environments, encourage blooms of cyanobacteria, whereas in temperate climates phosphorus limits the growth of microscopic algae.

The IRD's Cycoco research unit and the Bioecoco joint research unit (CNRS, ENS, IRMA), in partnership with the Senegalais des Eaux water

company, are conducting experiments on the Dakar-Bangor reservoir in Senegal. The work is funded by the Ministry for Ecology and is aimed at re-examining the mechanisms governing trophic cascades in tropical lakes. Because the chemical constraints are different and the trophic links looser than in temperate regions, ecosystem management and restoration must be based on different models.

Algal and bacterial blooms are fostered by economic development and global changes, but integrated ecological management can remedy them and ensure good water quality. For example, maintaining colonies of aquatic plants such as *Hydrilla* prevents the shift in trophic balance that would allow phytoplankton to proliferate. Limiting the inflow of nutrients, particularly phosphorus from fertiliser and sewage, also prevents cyanobacteria blooms.

Contact: [vauvrie.laurence@ird.fr](mailto:vauvrie.laurence@ird.fr)  
Publications: *Freshwater Biology* and documentary video for Canal RD



THE PARTNER



## \\ Farming system productivity

In many parts of the South, low farm yields combined with rapid population growth have led farmers to cultivate new land that proves to be unsuitable for agriculture. The result has been deforestation and land degradation.

The challenge now is to continue to increase food production to meet future needs, but without damaging or endangering the environment.

The goal of the IRD teams' most basic research is to improve yields from farmland while maintaining soil fertility, minimising erosion and reducing inputs. The scientists are working to improve understanding of plant biology and physiology and identify the genetic mechanisms responsible for specific varietal characteristics. Their findings will help speed the process of breeding varieties adapted to particular soil and climate conditions. Another crucial goal for improving crop yields is to control pests more effectively based on a more thorough knowledge of pest biology.

## \\ Food policy

Eliminating hunger, food insecurity and malnutrition while ensuring sustainable management of natural resources is a major development challenge. With today's rapid scientific and technological progress, it is now essential for government policies to take into account the needs of farmers, consumers and the environment together. The IRD's research in this field focuses on identifying appropriate policies based on incentive measures that local policy makers can introduce to improve the efficiency of food systems and encourage farmers to increase their output while managing their natural resources in a sustainable manner.



# Food security in the South



138 researchers

€20.44 million

172 scientific publications

## \Plant-bacterium symbiosis to limit the use of nitrogenous fertiliser

Nitrates from fertiliser applied to farmland often pollute rivers. But for many small farmers in Southern countries, even these fertilisers are beyond their reach. To improve farm yields without using nitrogenous fertilisers, scientists in the Tropical and Mediterranean Symbiosis Laboratory are exploring the symbiotic relationships between legumes and the bacteria that fix nitrogen directly from the atmosphere for the plant to use. The discovery of a hitherto unknown symbiosis mechanism opens up prospects for enhancing this kind of inter-species collaboration to a wider range of crop species.

Tropical soils are often deficient in nitrogen, which is an essential element for plant growth. Finding alternative solutions to nitrogenous fertilisers is a priority for sustainably ensuring food security in many Southern countries. Some leguminous plants can grow in nitrogen-poor soils by forming associations with soil bacteria called rhizobia. The rhizobia nourish the plant by drawing the nitrogen the plant needs directly from air in the soil. Legumes are an important food source for

humans and animals – peas, beans, peanuts, soybeans, clover and alfalfa, for example, are all leguminous crops. They are also an excellent choice for revegetating impoverished ecosystems, as they can act as pioneer species, the first species to settle on bare land and start the recolonisation process. But, despite its importance, the relationship between tropical legumes and rhizobia is not well understood.

The plant-rhizobium relationship results in the formation of nodules on the plant's roots. These are special organs made which the bacteria fix nitrogen for the plant's benefit. To form the nodule, a complex dialogue takes place between the two partners by means of signalling molecules called nodulation (Nod) factors synthesised by the rhizobium. This mechanism had been found in every rhizobium-legume partnership studied before now.

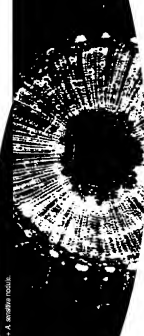
A recent study conducted by the IRD in collaboration with other French institutes (Ecoscope and CEA) and two American universities shows that this process is not universal. The scientists explored the association between an aquatic tropical legume, *Aeschynomene*, and a bacterium

of the rhizobium family *Bradyrhizobium*. This bacterium lacks the nod gene responsible for synthesis of the Nod factor, suggesting that there is some other way for a legume and a rhizobium-forming bacterium to work together. While the molecular basis for the new symbiotic process has yet to be pinned down, the scientists already suspect that the plant hormone cytokinin is involved in forming the nodules.

This discovery renews the hope of one day being able to get rhizobia to form symbiotic partnerships with non-leguminous plants of major agricultural importance, such as rice or wheat. It would then be possible to increase farm yields, especially in tropical countries, while reducing the use of chemical fertiliser.

Contexte: Verc. grande et fr  
Publication: Science 2007

+ A. sensitive nodules.



+ A. sensitive grown under glass/Wageningen.

At this joint laboratory the IRD works in partnership with Ouellet Anta Dop University (UCAD) and the Senegalese Institute for Agricultural Research (ISRA). The laboratory has more than twenty researchers, engineers and technicians working mainly on the natural diversity of indigenous symbiotic organisms, the conservation, optimisation and use of this diversity, how symbiosis works and the ecology of rhizobia and mycorrhizal fungi. It runs inoculation trials and monitors strains with a view to rehabilitating degraded ecosystems. Through its studies of rhizobial diversity and by isolating the strains it identifies, the laboratory is one of the links that led to the work of the Tropical and Mediterranean Symbiosis Laboratory on the symbiosis between *Aeschynomene* and *Bradyrhizobium*.

THE PARTNER



# Agroecology in Vietnam

The astounding economic growth of Southeast Asia, and of Vietnam in particular, is not without consequences for the environment. As increasing demands are made on the land, soils are becoming acidified, losing their mineral and organic content, and eroding. The nutrients they lose pollute groundwater and surface waters. The environment is jeopardised but soils the sustainability of the farming systems, with many consequences for human health. Vietnam today is facing the challenge of finding sustainable farming methods that will restore and maintain the quality of its environment.

Although models of sustainable agroecosystem management increasingly stress the importance of the role played by soil hum in ecosystem functioning, this factor is still poorly understood. Understanding and quantifying the roles played by species that act as "soil engineers" – essentially earthworms and termites – in soil fertility, carbon storage and erosion prevention is a significant issue for agroecology today. IRI scientists, in association with the Soils and Fertilisers Research Institute

in Vietnam and the International Water Management Institute are making a multidisciplinary study of this question, at various scales.

There is a strong link between cropping practices and earthworm species diversity. Systems based on matching deep microclimate in the soil and to encourage populations of anecic worms: these worms profoundly alter the fertility of a soil and its resistance to erosion. Their deposits constitute reservoirs of fertility where plant roots proliferate. Though the scientists have yet to pin down the consequences of this considerable root development for the plant concerned and for the surrounding plant community.

The activity of these worms also affects soil erosion and the parabolism of water into the soil. The macroporosity created by worm galleries opening to the surface and the increased surface roughness caused by the deposition of aggregates of biological origin make it easier for water to filter down into the soil, so reducing erosion and loss of nutrients through surface runoff.

Thus the abundance and diversity of soil fauna play an important part in maintaining soil quality and ensuring proper agroecosystem functioning. To assess this, IRI researchers are working on an indicator of soil aggregate signatures. The aim is to quantify the importance of biological activity for the dynamics of soil structure, the rate of organic matter, carbon storage and erosion. Specifically, the indicator is designed to tell whether soil aggregates are caused by biological activity or mechanical human activity such as tillage. Field experiments are currently under way to validate the results under controlled conditions.

More work is required on the role of soil fauna in erosion control and the soil fertility.

Contact: Pascal Jouquet at IRI  
Publication: *Biology and Fertility of Soils*

+ Assessing rice ripeness.

+ Organic fertilisation.

Founded in 1969, the SFRI is the main research institute working on soil functioning in Vietnam. Tasked by the government to conduct fertilisation research to assist the country's farming plan, the SFRI produces essential scientific knowledge for agriculture. To foster sustainable land use, the research is studying heavy metals pollution and focusing on organic fertilisation methods and the exploration of soil micro-fauna to improve yields. With four centres spread around the country, the SFRI covers the entire field of soil fertility science from soil microbiology to farming practice.

THE PARTNER



→ Access to health care: Senegal

## Public health and health policy



Access to health care is a priority in the social science of health and must systematically accompany any research undertaken in this field.

### Combating the main diseases linked to poverty: AIDS, malaria, tuberculosis

AIDS, malaria and tuberculosis are commonest in the poorest countries – sub-Saharan Africa especially. They undermine a country's economic activity and hamper development. To combat these scourges, apart from improving access to existing treatments, which is vital, it is also essential to intensify research and the development of new diagnostic methods and treatments, and to improve the quality of research in Southern countries.

### Environment and emerging diseases

Any sudden change in the natural environment such as deforestation, water engineering works or urbanisation, can facilitate the emergence of disease. Taking account of such environmental impacts on health is a recent advance in developing countries. These countries are facing profound changes, both environmental and social, and they have become incubators for new diseases such as SARS and bird flu that are making an impact worldwide. Meanwhile the developing countries are no longer spared the diseases of civilisation. Health research requires an ecosystemic approach that will produce methods applicable to local situations and solutions that are viable over the long term.

### Mother and infant health

Women are especially vulnerable with respect to health because of the risks connected with pregnancy and childbirth. And through their childcare role, they also ensure the health of future generations. Reproductive health, the risk of mother-to-infant transmission of the AIDS virus, malaria in pregnant women and factors that can affect the health of mother and infant are therefore important aspects of the IRD's health research. Similarly, the roles and work society allocates to women (a long-neglected factor, along with gender inequalities and gender issues in general), should be essential strands of research, especially in terms of their impact on health.



# Synergy between insecticide and repellent to combat malaria-carrying mosquitoes

With 40% of the world's population, mainly in the poorest countries, exposed to malaria risk and over 500 million people falling ill with the disease each year, it is still the most worrying tropical parasite disease. Most deaths from malaria occur in sub-Saharan Africa and most of those who die are young children or pregnant women. Although the World Health Organisation strongly recommends the use of mosquito nets impregnated with insecticides, such as pyrethroids, the development of resistance to these chemicals has prompted IRO researchers to develop new products that harness synergy between insecticides and repellents.

To protect populations against *Anopheles* gambiense, the principal vector of human malaria in Africa, the World Health Organisation recommends the use of mosquito nets impregnated with insecticides of the pyrethroid family. These chemicals are not very toxic for humans or mammals and can be effective against mosquitoes at very low doses by combining several effects: they are toxic, killing the insect or knocking it out as

soon as it touches the net. They are also repellent, limiting the numbers of mosquitoes that enter a bedroom. And they are irritant, so preventing the insect from biting through the mesh of the net. However, excessive or inappropriate use of these products has led to a worrying increase in the numbers of resistant mosquitoes and the risk that the impregnated nets will lose their efficacy.

As there are few replacement insecticides, IRO scientists in collaboration with their Benin and Burkina Faso partners combined a non-pyrethroid insecticide with a repellent in order to reproduce the same properties as the pyrethroids without using those chemicals themselves. A strong synergy was found between insecticides and repellents: the combination proving far more effective than the sum of their respective properties. Further, the efficacy lasted several weeks longer than with each chemical on its own. The combination proved especially advantageous because it can be used for impregnation at far lower doses than the pyrethroids to achieve the same effectiveness.

Industry is beginning to express interest in this synergy concept, developing micro-capsule formulations with repellents and insecticides and experimenting with long-lasting impregnation. Alongside these field studies, laboratory research is trying to improve understanding of the action of the repellents and insecticides on the mosquito's central nervous system and the mechanisms involved in the synergy.

Contact: [Niam-marchand@iro.ird.fr](mailto:Niam-marchand@iro.ird.fr)  
Publication: *Malaria Journal* (2007)

• Testing for malaria.

• Anopheles larva.

"Combat malaria through a better understanding of mosquitoes" could be the motto of the CRC. Its scientists are exploring every avenue: vector biology and characterisation, insecticide resistance, evaluation of control measures, therapeutic trials, qualitative studies and monitoring of impregnated mosquito nets. Although these ambitious goals require infrastructure and human resources, partnerships with major institutes in the North are helping to make up for the lack of a qualified research staff in Benin. Partners include the IRO, CIRAD and the Centers for Disease Control and Prevention in Atlanta, USA. Today the elimination of malaria is still a challenge; tomorrow it may become a reality. One avenue is to build African research capacity. The CRC has been providing training since 2003, but a project is now under way to extend the Centre and build a fully-fledged epidemiology research and training institute that will also host young African researchers.

## Identifying reservoirs and genetic lineages of the Ebola and Marburg viruses

The devastating haemorrhagic fevers caused by viruses of the Filoviridae family in Africa have been known for some thirty years. These viruses, harboured by fruit bats and transmitted to humans, have caused deadly epidemics resulting in hundreds of deaths. To develop vaccines and protect the population, scientists must learn more about their natural reservoirs, their transmission pathways to humans and the mechanisms by which their genomes evolve.

The filoviridae Ebola and Marburg are a formidable family of viruses responsible for numerous outbreaks of haemorrhagic fever in Africa, but little is known about them. Eleven outbreaks of the Zaire Ebola species have killed nearly a thousand people – over 60% of cases. The Marburg virus is less widespread, with about 300 deaths recorded in the 1960s and 2005 outbreaks in the Democratic Republic of Congo and Angola.

To make headway against these diseases, scientists have been trying to identify the viruses' original animal hosts (their "reservoirs") to

understand how they spread to humans and to see how they evolve. In 2005, IBD researchers identified three species of tropical bats as natural reservoirs of Ebola virus, but it was not until 2007 that the same team, in partnership with the International Centre for Medical Research in Francfort, Gabon, and the Centers for Disease Control and Prevention in Atlanta, USA, identified the Egyptian Fruit Bat or Egyptian Horseshoe (Rousettus aegyptiacus) as the reservoir for Marburg virus.

While identifying the reservoir is essential for demarcating the area affected by the virus and taking hygiene measures to limit its transmission to humans, it is equally important to develop a vaccine. And for this, it is vital to discover the mechanisms by which the virus's genome evolves. With the Zaire species of Ebola virus, the IBD scientists and their partners have identified a new genetic lineage which is thought to have diverged from the known lineage before the first Ebola epidemic in 1976. The new lineage includes the strains responsible for the last two outbreaks and all the strains isolated from the great apes. The research has also shown an evolutionary phenomenon hitherto unknown in this virus family and very rarely observed in any negative-

sense RNA virus: genetic recombination between two lineages. This mechanism is thought to have empowered the virus group responsible for the epidemics that occurred between 2001 and 2003 in Gabon and the Republic of Congo.

These discoveries raise new questions as to how Ebola virus emerged in humans and the great apes. They also suggest that there are unknown strains circulating in the wild. It remains to establish a complete genetic map of the different strains and locate the gap in the genome where genetic material is exchanged. Understanding the genetic recombination mechanisms in Ebola virus is an indispensable step for developing vaccines based on weakened virus.

Context: Vincent Jarraud, Director of the National Academy of Sciences of the USA (2007), Paris ONE

+ Bush laboratory/Gabon

+ Egyptian Fruitbat, reservoir of the Marburg virus



THE PARTNER

Mélanie, retroviruses (HIV, SIV), viral haemorrhagic diseases (Ebola), the CRMF is proving its value as a cutting-edge partner for medical research into these pathologies. The centre has more than 2,500 m<sup>2</sup> of laboratories in Francfort, Gabon, equipped with the most advanced equipment to conduct cutting-edge research in molecular and cell biology. While the Centre's main aim is research, it is also involved in training young researchers from all over the world. Its third role, and not the least, is public health support. It makes its competencies and structures available for this purpose and conducts epidemiological studies in the field.

In this connection the IBD has seconded a young team to help run the CRMF's Emerging Viral Diseases laboratory. This unit takes a multidisciplinary approach combining genomics, phylogeny, host immune responses, inter-species circulation of the virus and the conditions for emergence of epidemics. Its various technical facilities and logistical field resources function in synergy to support this approach.

## \Reducing poverty and inequality

To reduce poverty and inequality, this is a major goal for development policies and one of the goals the international community has set itself. IRD research addresses the issue from several angles: the multidimensional aspects of poverty (monetary, human, time-related etc.); access to public services such as education, health, water and transport; the operation of the labour market; and the impacts of public and private development aid.

## \International migration and development

The globalisation process has accelerated the movement of the factors of production but has curbed the movement of labour. Population movements across the world's main fracture lines have intensified (e.g. Europe /North Africa /sub-Saharan Africa) especially where the income gap is widest. This has made international migration a major issue for development.

The IRD's research in this field has several focal points: the determinants and consequences of migration on societies and environments; the measurement of mobility at the levels of town, region and country and its impact in terms of territorial and social recomposition; the formation of networks and diaspora organisations and the reshaping of identities as a result of migration.

## \Better governance for sustainable development

This research contributes facts and ideas towards sustainable development in developing countries – development that will combine economic growth with environmental protection. The research is at the interface between societies and nature, but also at the interface between local practices and official and international policy on biodiversity conservation and environmental management. It takes account of local practices and how they can contribute to defining an improved form of governance, one that would be at once appropriate, accepted and efficient. The two main aspects considered are access to and conservation of resources, and urbanisation and access to services.



# Development and globalisation



193 researchers

€21.14 million

400 articles and books

## Globalisation and countries of the South: disparities and solidarity

While globalisation is intended to turn the world into one "global village" where countries and individuals will all have access to the same development possibilities, in the South the process is showing clear disparities between different countries and regions. Integrated as a process of homogenisation, for Southern countries it is proving to be a source of inequalities. The concept of territory needs to be rethought on different regional, national and supra-national scales to rebuild local and global solidarity.

What place is there for Southern countries in globalisation? How are hierarchy and solidarity to be built between stakeholders at the local and supra-national levels? Starting from studies conducted in ten countries of Africa, Latin America and the Indian Ocean, in 2001 the IRD and the Ecole normale supérieure in Paris launched a two-year programme on *Territories and Globalisation in Southern countries*. Some forty researchers from North and South in several social science disciplines

set out to provide partial answers to these questions and improve understanding of the globalisation process in Southern countries.

In Brazil, states compete to attract investment by offering financial advantages. In Lambayeque, Peru, communities of smallholder mango growers have been marginalised by the production and marketing methods of large farms nearby. These are just two examples of the way globalisation transforms hierarchies between territories. Some, like the poorest fronts in the Amazon or the townships of Johannesburg, directly linked to the world economy, concentrate benefits, while others are unable to meet the demands of the global market. In this very disparities and competition between regions arise. Public policy privileges territories that are attractive to foreign investment and the development of infrastructure and facilities. Production zones and transport patterns shift according to a global logic, rather than the rationale of the countries and regions concerned. A few major routes are privileged to the detriment of more diversified transport networks.

these routes connect major economic centres but leave the territories they pass through literally by the wayside of development.

To combat this increasing spatial differentiation, the researchers suggest rethinking the concept of territory, taking into account the different scales involved: region, country, supra-national space. Establishing (or re-establishing) territorial solidarity, from the local level to the global, requires political will and an active role for government in establishing better balances of investment and its effects between interlinked centres and local markets. For there to be new development potentialities for all, such terms of solidarity must be constructed and a proper balance between openness to and protection from globalisation must be sought.

Contacts: [jerome.lombardo@ird.fr](mailto:jerome.lombardo@ird.fr) [erelyne.mesclard@ird.fr](mailto:erelyne.mesclard@ird.fr)  
Publication: *La mondialisation code sud - Acteurs de territoires*, IRD Editions

+ Cape District/South Africa

+ Oman/Arabia



+ Bus, Shikhar/Vadast



THE PARTNER

Cheikh Anta Diop University (UCAD) in Dakar was founded in 1957. It is made up of a number of faculties, institutes, etc. which between them cover most of the subjects addressed in higher education. The geography department of the Faculty of Letters and Human Sciences is particularly closely involved in the *Territories and Globalisation* programme, for which it has been researching into the future of urban and rural transport in a local situation influenced by the international aid donors. For four years postgraduate geography students worked on the programme and attended seminars with researchers from IRD and UCAD. These regular exchanges and the continual sharing of information were informative, fruitful and enriching for all the participants.

# Environmental approach to urban change in Addis Abeba

Most major cities in the South are a concentration of deep poverty and chronic lack of infrastructure, with excessively rapid urban growth causing major environmental degradation. This situation raises many questions for sustainable development. IDO researchers are taking an environmental approach to urban transformation and suggesting avenues for a more sustainable form of development for Southern cities, based on better use of the existing social, cultural, natural and material urban environment.

Ethiopia is one of the world's poorest and most rural countries, with only 16% of its 77 million people living in towns. The new government policy is to rely on the cities as the economic driving force for national development, but this perspective presents a challenge. Can there be a form of urban development that meets this policy choice but remains locally sustainable? To elucidate this question, the IRD has been examining the dynamics of urban transformation in Ethiopia to clarify its characteristics and identify long-term trends.

One disquieting risk often mentioned in connection with the growth of the capital, Addis Abeba, is that it will become an increasingly divided city where the situation and urban life of the better-off is increasingly far removed from those of the poor. However, the surveys conducted highlight several factors that hold promise for sustainable urban development. For example, its compact housing style is economical of energy and materials, and its geo-social proximity is a factor for peace and security and also generates employment.

The researchers developed an "environmental" method for studying the city. This consists of monitoring urban change in terms of the needs it entails and the desire to conserve and pressure that it exerts. This approach reveals local potentialities and vulnerabilities, both of which are key factors that must be identified for planning urban transformation. The approach has been well received by decision makers and was adopted, for example, in an ecology experiment the city council conducted in 2004 to rehabilitate Addis Abeba's poor neighbourhoods. The programme has

also been important in increasing awareness among public authorities and international aid agencies of the constraints on urban development in Ethiopia, but also its original potentialities.

The programme began in 2001 and is continuing with the support of the French Centre for Ethiopian Studies, in scientific partnership with the Ethiopian Civil Service College. The methods and the research-based training accomplished in Addis Abeba are now being awarded to other regional capitals. This includes making the knowledge acquired and the information collected as accessible as possible to all the stakeholders concerned.

Contact: [Adomique.courteille@ird.fr](mailto:Adomique.courteille@ird.fr) [bezunesh.tamru@univ-jen2fr.fr](mailto:bezunesh.tamru@univ-jen2fr.fr)  
Publications: *Annales de la Recherche Urbaine* n° 97 (2004);  
Dissertation for research director's qualification,  
Bezunesh Tamru (2007)

↑ Ancient and modern housing/Addis Abeba.



↑ Poor districts/Addis Abeba.

The Ethiopian Civil Service College trains managers for Ethiopia's regional and municipal authorities. It awards Bachelor's and Master's degrees, many in law, planning and territorial development, public policy and development management studies. Most of the teaching takes place in three main faculties in Addis Abeba and there is also a distance learning department.

The IRD is supporting the college to establish an Ethiopian urban research platform in partnership with the University of Addis Abeba.

THE PARTNER



# Addressing ethical issues

The IRD's Consultative Committee on professional conduct and ethics (CCOE) was created in 2000. It works to establish and develop the rules of professional conduct in research for development, to formulate the ethical questions involved in fieldwork and to help researchers take them into account.

In 2007 the CCOE was asked for its opinion on some twenty issues, as research teams submitted projects for ethical assessment. One of these concerned environmental issues, the rest biomedical research. At the latter concerned infectious diseases, and half of these concerned malaria. The Committee was also asked for advice on professional conduct and ethics with regard to database property rights, ethnic discrimination, conflicts of interest, etc.

The Committee continued its examination of "the ethics of scientific communication" and started to consider the question of "right of personal portrait", starting from questions raised by IRD staff. The Committee will publish its opinions on both these issues in 2008.

During the year, the CCOE took part in twelve symposia on such themes as "Science and societal change", "Scientific integrity", "The precautionary principle" and "Ethics in health research in Southern countries".

The Committee worked with the French and Senegalese commissions for UNESCO to prepare a cooperation forum on bioethics and medical ethics. This was held in Dakar and brought together participants from 12 countries including France, India and ten countries of West and Central Africa. The CCOE gave talks on "Women's role in society and in health decisions", "Taking vulnerability into account" and "Partnerships among ethics committees".

The Committee joined forces with the IRD Societies and Health department to design a workshop on "Shared responsibility in the human and social sciences" open to human/social science researchers from the IRD and other institutions. The aim is to explore avenues for appropriate ethical practices in social science and to stimulate constructive thinking about the best forms of collaboration with a partner country where social science research is being conducted.

There are two more major projects in their planning stages. One is to set up training in ethical thinking for members of ethical committees and for researchers in the IRD and in partner countries. The other is to hold a seminar on "Research ethics, cultural diversity and development". The latter will be open to scientists from North and South working in any of the fields the IRD covers.

• Musée génétique research Montpellier

## Chair:

Professor of philosophy, Denis Diderot University (Paris 7)

## Members:

Researcher, Institut de Investigaciones Sociales, Autonomous National University Mexico

Honorary President, Forum for African Women Educationalists, Cameroon

Dietrich European Centre for Research and Advanced Training in Scientific Computation

Professor, CNRS-University of Nice Sophia Antipolis joint Organic Chemistry Laboratory

Associate Professor of Science Journalism, Pompeu Soler University, Barcelona, Spain

Research engineer, Camelia research unit plant pathologist, former director of the IRD

Centre in Berlin

anthropologist, HWAIDS and associated diseases research unit

**Recruitment** mobility, job content, the IRD's scientific decision bodies assess researchers and laboratories to ensure a high level of research performance. The number of publications – a good gauge to the quality of the scientific output – had already increased by 20% in 2006, in 2007 it increased by a further 10%. Research activity at 6,500 hours, was comparable to the previous year.

## Ever more stringent evaluation

AV 2007 marked the end of the four-year mandates of the four sectoral scientific committees and the two committees managing the research and its specific areas. They examined about 500 researchers' files, either for routine assessment or with a view to promotion. They continued to improve their researcher evaluation criteria in line with the most stringent international standards.

These committees provided most members of the admission juries for the year's 28 competitive external recruitment claims. They interviewed 420 candidates, a figure that reflects the level of competition to join the IRD.

Concluding their mandates, the scientific decision bodies also concluded the last round of internal IRD assessments of proposals to create, extend or merge IRD research units (5 proposals) or joint units (25 proposals), including six for international joint units). Hereafter, all unit assessments will be conducted by the national evaluation agency AERES.

## Publications: over the 1,000 mark

Not counting the social sciences, the number of publications by IRD researchers in 2007 was close to 1,000, including articles by joint units in which the Institute was involved, the total was 1,830. Over the past ten years, the annual publications' count has increased by 75%, compared to 21% for French scientific publications as a whole. As evidence of the quality of the output, 9% of the journals publishing IRD researchers' articles were among the leading 1% of the journals publishing research articles in the *Journal of Horticulture*, 6 in *Arctic Science of Environment*, 4 in *PLoS*, 4 in *Nature* and 2 in *Science*. Over 58% of articles were published in the top 25% of scientific journals. With an output of 1.7 articles per researcher per year, the IRD ranks 18th among French research bodies in the *Web of Science*.

IRD researchers were far ahead of the French average in the practice of joint publication, producing 96% of their articles jointly with outside partners. In most cases (65%), this involved international partners, 43% being jointly published with Southern researchers. The main partner countries were France, Senegal, Cameroon, Mexico and South Africa.

## Teaching and supervision

Accompanying its drive to create joint research units with other institutions, including universities, the IRD is steadily increasing the amount of teaching and researches provided. In 2007 they delivered 6,500 hours of teaching, half in Southern countries (mainly in Africa) and the rest in France, very largely concentrated in Ile-de-France, Montpellier and Marseille. Increasingly, the teaching is part of permanent training courses and reflects the well-established close collaboration between IRD teams and particular doctoral schools.

A total of 750 doctoral students were supervised in IRD units in 2007 and 138 of them presented their theses during the year. More than half (60%) were from Southern countries. The IRD is also playing an increasingly significant part in Master's level training: 300 students who had been supervised by IRD scientists presented their Master's dissertations in 2007. Over 40% of these students came from Southern countries. Altogether, IRD units and laboratories accommodated 700 interns working for their Master's or Diploma degree.

The professional training provided by IRD researchers and engineers is mainly intended for scientists from the South. It consists of introductory or higher level training in the use of new measurement tools and methods or the practice of specific analysis and investigation techniques. In 2007 it represented an investment of 2,600 hours.

Contact: [ds@ird.fr](mailto:ds@ird.fr)

# Evaluation, publications and teaching







# TRAINING, sharing, finding applications

to Southern  
country researchers and students

held



# Support for Southern scientific communities



2007 marked a crucial stage in the convergence between several approaches designed to help build scientific capacities in the South. The "New IRD partner teams" programme (UEA, Jeanes equips associates a IRD) gained recognition as a factor in structuring new teams and building their self-reliance; the international Masters' degree in medical entomology was launched; and the IRD was working more closely with doctoral schools. All these reflect the consistency of the capacity-building policy that is part of the IRD's long-term strategy. That policy has been sanctioned by the ISO 9001 certificate awarded to the structure in charge of organising and managing calls for proposals in connection with capacity building.

## Support for individual u.s

The IRD supported 195 projects by Southern country researchers, including 75 new projects. This support took the form of thesis grants (144), in-service training grants (31) and scientific exchange grants (20). The 20 thesis submitted and the ever growing proportion of these proposals presented by Omer and JEN teams show that these instruments are well matched to the needs of young researchers. They also show that the different provisions for building research capacity in Southern countries complement each other well. Project monitoring showed that grants had especially strong impact where the work was part of an integrated project.

APPLICANTS	DURATION	PURPOSE	ASSASSMENT
These grants Graduates with a Masters 2 degree	up to 3 years	Initial training of Southern researchers	Housing and supervision in teams at IRD or its partners
In-service training grants Graduates at researcher, engineer or technician level	12 months over 4 years	In-service training or professional upgrading	Partnership between IRD and employer institution in South
Scientific exchange grants Researchers	12 months over 4 years	To encourage mobility	Partnership between IRD and employer institution in South

## Support for a team

Since 2002, the Institute has been supporting the emergence of new research teams in the South through scientific partnerships with IRD research units. This year 8 such teams (UEA or Jeanes equips associates a IRD) were selected joining the "already in the system". There are 4 UEs in Africa, Latin America and Asia, and in 2007 they received a total of €6713 025 in funding from the IRD (compared to €6 300 000 in 2006).

To foster these teams' ability to continue over time, become self-reliant and increasingly integrate into the international scientific community, the IRD holds annual workshop encounters where new researchers can share experiences and learn about the more cross-cutting aspects of the researcher's role – team management, knowledge of the research environment, writing up projects, integrating young researchers, finding economic applications for results.

Twenty-one of the first JEUs selected since 2002 have come to the end of their financial support period. The Chair of the IRD's scientific council had an assessment made of the system. This showed that creating a JEI makes a significant contribution to structuring research in the South because these teams continue their work owing to the leverage effect of the grants. Although the results in terms of international publication output is still modest, the JEUs are playing an active part in research-based training. Many of them have a real potential to become self-reliant entities. The role of the partner IRD unit, which is mainly to provide support as the JEI sets up and implements its project, seems important in this respect. One JEI team leader obtained a part-professorship with an IRD researcher.

## Stronger ties with universities

The first two modules for the international Masters in medical and veterinary entomology in Boran (see box) comprise 25 students from countries in Africa, Europe and Latin America. In partnership with Havana Noel University in South Africa, the IRD also organised a summer school in hydrogeology of degraded soils.

In Bolivia, the Masters in environmental science launched in 2006 by the Universidad Mayor de San Simon in Cochabamba took in 20 students, ten of whom obtained grants thanks to IRD funding. The "virtual" Masters in human geography set up in partnership with the Universidad Mayor de San Andres in La Paz is also a success.

These Graduate and research associates in Southern Africa are supported by the IRD and European Union. The programme is a success story in part by the IRD.

• Self-made.

# • JEAI mathematical modelling team wins International recognition

One of the young IRD partner teams is LMOP, the Mathematics and Population Dynamics Laboratory led by Moulay Lhassen Haddi of Gafsa University, Marrakech. The team's population dynamics research concerns sardine fishery system dynamics, forest plant populations, urban communities and epidemiology (studying how epidemics spread). Over a period of ten years the team has produced numerous high-quality publications and developed a close and fruitful partnership with the Gerdas unit. It has taken part in building effective mathematical modelling networks involving both Northern and Southern partners. These networks have won funding from a number of outside sources, which is an unmistakable sign of international recognition of their worth. This recognition is also reflected in the team's many contributions to international symposia and the international conferences, specialist workshops and summer schools it has organised. Thanks to its acknowledged expertise the team has supervised many doctoral theses and taken part in creating several Masters courses. Now a permanent, independent entity, the team is planning to further strengthen its structure by joining an international joint research unit.

Closer relations with doctoral schools were initiated. The IRD hosts cross-cutting training sessions on 'the researcher's profession' for doctoral students. These now lead to a certificate issued by Agropolis's doctoral school. AIFS (agriculture, food, biology, environment and health), which will be taken into account in validating their theses. Meanwhile, at the seminar presenting the results of the ECrime project for a Euro-Mediterranean research area<sup>2</sup>, a theme-based training workshop (where) was held for doctoral students from the Mediterranean region.

This commitment of the researcher's profession was also pursued at the Young Researchers Days at Chloé Anja Drey University in taking jointly organised with the IRD. This event was designed to build more bridges between research and the socio-economic fabric.

## After the funding: self-reliance and networking

As announced at the first workshop encounter for JEAIs a collaborative workspace is being planned to facilitate the JEAI teams networking and promote self-reliance.

Contact: [csd@ird.fr](mailto:csd@ird.fr)

By 2007 the researcher's team<sup>3</sup> training days were held in the body of the IRD in Montpellier and in the framework of the 10th International Conference on the Role of the University in the Mediterranean.

• Malaise vector Anopheles gambiae



At a time when vector diseases are making a major comeback, entomology teaching and the number of entomologists are both in decline. Faced with this fact and in response to strong demand from the South, the IRD designed and organised an international Masters degree in medical and veterinary entomology, open to African and European students. The course prepares students for research in the biology, systematics, ecology, population genetics, genomics, post-genomics and control of disease vectors. It comprises theoretical classes at the Regional Public Health Institute in Oran, Beni, practicals at the Entomology Research Centre in Cotonou, and fieldwork in endemic areas. Most of the host laboratories for the research placements are in Europe and Africa. The course is funded by the three above-mentioned institutions and is offered by two universities, Abomey-Calavi in Benin and Montpellier 2 in France.

• Students on the medical entomology Master's course Beni.



# Applications and consulting

Finding applications for research results and researchers' technical knowledge for the benefit of Southern countries' economies and society is a core mission for the IRD. It is to this end that it manages its intellectual property, helps investors set up in business, conducts institutional and individual consulting missions, and expert group reviews and establishes partnerships with industry.

## Expert group reviews for sound policy decisions

One of the IRD's essential missions is to inform decision makers and enrich public debate on crucial issues connected with development in Southern countries. The tool it has developed for this is the expert group review, a round-up and analysis of scientific knowledge at a given moment on a relevant issue. At the behest of an external commissioning body, the Institute gathers together a multidisciplinary group of experts and gives them a one-year deadline to assess the state of knowledge on an issue and draw up recommendations that are discussed with civil society.

In 2007, two expert group reviews were delivered to their sponsors at a seminar in Bamako, Mali, and their recommendations discussed:

- **Trachoma control in sub-Saharan Africa**  
Trachoma is the world's second most common cause of blindness. It is an infectious disease in which "the eyelashes grow inward". Although it can be prevented and treated, it still affects nearly 10 million people, especially in sub-Saharan countries. What needs to be done? How are the measures already taken to prevent or cure this disease to be assessed? What is the situation with trachoma control and what recommendations can be made to eradicate the disease? At the behest of the African Health Ministry and the Institute of Tropical Ophthalmology in Bamako, the IRD conducted a review to answer these questions. IRD researchers brought together by the IRD assessed the results of current strategies and proposed a five-year plan of action.

- **Future of the Niger River**  
The Niger River is a vital source of water for West Africa, and for the people of Mali in particular. Its waters are used for electricity generation, irrigation, navigation, urban water supply, fishing and aquaculture – a multitude of uses which sometimes have to compete for the resource. In Mali, remarkable traditional production systems based on the river's natural flood cycle coexist with major modern water engineering works for hydroelectricity and farm irrigation. In this situation proper management of the resource is a major challenge. The expert group review conducted by the IRD and the Institute of Rural Economics in Mali gives an all-round assessment of the state of health of the river and to many uses. It explains the implications for the river's future of existing management and use patterns. The reports' proposals are aimed at clarifying the institutional frameworks and public-policy options for managing the Niger's water resources and strengthening monitoring and decision aid tools.

## Consulting

Companies, civil society organisations and public bodies such as ministries and local government often call on the expertise of the IRD's researchers and engineers to conduct surveys, propose technical solutions or analyse situations. This year the IRD signed 15 institutional consulting contracts with customers that included the following:

- **Gaston Berger University in Saint-Louis, Senegal**, to help assess the University's research and draw up a strategy plan.
- **the Goro Nickel mining company in Mauritania, New Caledonia**, to produce a reference base for the physico-chemical quality of local waters and their concentration in dissolved metals in the rainy season.
- **the national forestry authority in Cote d'Ivoire, French Guiana**, for an inventory of flora and to train forestry staff to identify plant species at the landscape site;
- **the Société du Canal du Provence, a French private company**, to assess the water level of the Senegal River at Dioppe, Mauritania, at peak flow under the influence of the Meslental dam.



+ Expert group review on the River Niger (Mali).

### ▼ Innovative company formation

The Institute provides support for staff with projects to create innovative companies, at the stage of technical validation and preliminary assessment of their projects economic feasibility. It then advises and supports the entrepreneur in their applications for the relevant national support measures.

- RD engineer wins national competition for company formation support. Didier Lalle, research engineer in the Espace service unit, working in New Caledonia, was the main prize-winner in the 5th national competition for innovative technology companies, financed by the Ministry for Research and Higher Education to encourage such company formation. He received €350,000, the highest award in the competition, to develop his Bluebeam enterprise project: the product is a bio-sensor and system for environmental issues incorporating the latest technologies in remote sensing, thermal technology and applied mathematics.

### ▼ Intellectual property

The RD continued its work of identifying innovation in its laboratories and consolidated its international portfolio of patents. Eleven patentability studies were conducted by outside consultants and four new patents were applied for, taking the number of patents held by the RD to 57. These patents fall into three main categories: biotechnology and health technology (77%), environment (12%) and instrumentation (11%). Twelve patents are jointly owned with industrial firms and 9 with the academic sector. Four are jointly owned with Southern institutions.

Inside two industrial property licensing contacts with private enterprise are under way. A new industrial partner, Sweden, which commercialises marine biotechnology, signed a contract with the RD in 2007, to screen thermophilic bacteria from the Microbesol variant.

Preliminary contact was established with the African Intellectual Property Organisation (AIPPO) to explore the possibilities for improved protection of our patents in Africa.

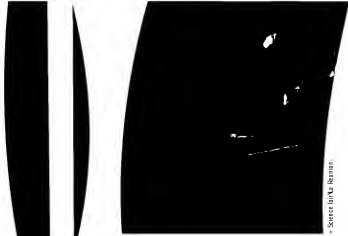
The Institute also continued to raise awareness of intellectual property through seminars in France (Grenoble and Soest, Lunasol and Sonegal).

Contact: [Vale@rd.fr](mailto:Vale@rd.fr)

• Bluebeam, environmental decision aid system.

• Chagas disease control device.

# Communication and knowledge sharing



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The IRD invests extensively in sharing its scientific assets – the knowledge it has amassed over the past sixty years. This also brings the Institute recognition from partners and a higher public profile. As development issues attract the attention of an ever wider public, the IRD's communication drive gains strength. The Institute employs a wide range of communication media from books, films and exhibitions to information sheets and electronic publishing.

## Ultimedia and written communication

Nearly 20,000 articles published in the press in 2007 reflect the degree of public recognition of the Institute's work. *Sciences au Sud*, the IRD's bimonthly newsletter, whose 15,000 copies are distributed in 120 countries, is also available on the Web, with more than 500,000 page hits. It is also gradually opening its columns to the IRD's partners.

Twenty-eight new information sheets were published in 2007, adding to the 230 previously published.

The IRD's websites received nearly 4.2 million visits in 2007 – an increase of 30% over the previous year. In July 2008, the image base is also expanding. It now has 40,000 photos available online.

The IRD produced 53 books and atlases in 2007, as well as films, some of which have been broadcast on television in France or abroad. Examples are *Chercheurs de l'IRD* (co-production with TV channel France 5) and *Joghiké, prince des réserves*, a film about the Mafa of Cameroon.

Among the books that attracted attention, *Les globes à l'épreuve du climat* gives a panorama of the state of the world's globes and *Les marches de la biodiversité* casts a critical light on the biodiversity conservation model based on its commercial exploitation.

On the cartography side, the IRD publishes atlases and multimedia products. This year's big map publishing event was a map of the hydrographic basins of West and Central Africa.



AFRIQUE DE L'OUEST ET CENTRALE  
BASSINS HYDROGRAPHIQUES  
Claudine Desclaux - IRD

Laboratoire de cartographie, 2007

## Raising public awareness

Most French people consider themselves under-informed about scientific research, and one aspect of the IRD's work is to foster exchanges between scientists and the general public. In 2007 some hundred researchers helped to improve communication between science and society by giving talks or taking part in public debates and science fairs.

More than forty partner countries and some twenty venues in Metropolitan France hosted the IRD's travelling exhibitions on major themes in research for development including water, climate, natural hazards and population. The *Sciences au Sud* exhibition was displayed in six towns in Senegal and Mauritania. It was visited by pupils from more than a hundred high schools – nearly 12,000 guided exhibition tours were provided. The exhibition *Océan et climat* earned the International Panel Earth Year award from the French Academy of Sciences.

Africa was again the region where most outreach activities took place. More than 112 projects in ten countries were funded from the *Partners' Solidarity Fund* for the provision of scientific culture, which the IRD administers on behalf of the Ministry for Foreign Affairs.

### Mobilising the younger generation

As part of this drive to raise scientific awareness among the young, twelve new IBO Clubs were created in 2007. Of the 23 existing clubs, 12 are involved in running the *Soleil jaunes* program that is mobilising young people to combat the AIDS pandemic. Other actions this year were designed to raise awareness about biodiversity and about education for sustainable development.

### Disseminating scientific and technical information

In forming a

On the documentary resources side, the IBO pursued its commitment to making scientific publications freely available, especially to Southern countries. It played an active part in setting up the IRII open archive platform, a resource shared by all French research bodies and universities. To encourage researchers to play their part in this policy of free access to scientific information, an "open archive deposit charter" was circulated towards the end of the year. *Héron/Plains* besides the publications base that stores the IBO's research results, holds 67,000 documents including 37,000 in electronic form. The website receives some 50,000 visitors a year, who download over 20,000 documents a year.

Dissemination and popularisation of research results are essential aspects of the IBO's work. Providing access to scientific and technical information also narrows the digital divide between North and South, another crucial aspect of the Institute's mission.

Content's close link



• Sciences au Sud exhibition/Saint Louis.

• Documentation centre/Guadeloupe.





# WORKING in partnership



## Latin America Caribbean

250 conservation and engineering  
68 technical grants awarded  
11 new Southern research teams supported

### Latin America

- Launch of regional programmes in Mexico helped coastal ecosystems, sports clubs and birdlife, populations of African descent
- 13 AMT projects: climate, astronomy, agriculture, hydrogeology, health, movement, migration
- First ice core drilled on the San Valentin glacier in Chilean Patagonia
- First joint of cooperation with Peru
- International Africa conference in Chile
- International conference on Mining pollution, environment and health, in Chile

### French Guiana

- Satellite monitoring of Amazonia for environment and health (SEAS) (ongoing programme)

### Mexico City

- Showcasing innovation to science pedagogy into the art of the Labor Juntas

## Mediterranean basin

56 conservation and engineering  
20 technical grants awarded  
1 new Southern research team supported

- Five years of cooperation with Turkey celebrated
- International Eastern conference on assessment of scientific and technological capability in Mediterranean countries
- International seminar on socio-economic reconstruction in face of globalisation and its challenges
- Presentation of the results of the Mergans Programme on integrated water management in the Merquillo basin

## Asia/Oceania/Pacific

- 217 researchers and engineers
- 10 institutional grants awarded
- 3 new scientific research teams supported

### Asia

- Integration of the Institute for Tropical Diseases and Sciences at the University of Malaya
- Expansion of the Centre for Excellence on Vector and Vector-Borne Diseases (CEVBD) - Malaya research platform (Mahidol University, Thailand)
- Micro-anti-infectious agents: prevention and treatment of HIV/AIDS
- Fish farming in Indonesia and Vietnam
- Antimicrobial resistance in Tibet
- Meeting with Lao and Thai health specialists on the Greater Mekong region

### New Collaborations

- Creation of the Nickel and Environment Centre
- Application submitted to French Union for the New Development fund, made in World Heritage
- French Polynesians
- Agreement for the creation of a Polytechnic centre for research on and commercial use of land biodiversity
- Fostering of French Polynesians' political crisis

## Africa/Indian Ocean

- 400 researchers and engineers
- 10 institutional grants awarded
- 3 new scientific research teams supported

### Africa

- African programmes: interactions between ecosystems, climate and societies in West Africa
- Comparative survey under the AMMA programme (terrestrial and aquatic environments)
- Expert group: better knowledge control in the countries of Sub-Saharan Africa
- Expert group: water flows of the Niger River
- One-day workshops for new researchers in Dakar
- Research on the urban environment in Accra, Abidjan, Elgaba

### Madagascar

- International conference on tropical soils

### La Réunion

- Launch of the CHU centre for research and surveillance on emerging diseases in the Indian Ocean
- International conference on Chikungunya and other arboviral diseases involving 11 participating sites

# International



• Checking tuna catch watersheds

The IRD's new site policy is designed to foster closer international partnerships. In 2007 these were indeed strengthened, especially in Africa and the Mediterranean basin. The Institute worked to promote regional pilot projects on its priority themes and to make sure that research for development is properly taken into account in the European Research Space.

## Africa and Indian Ocean

In 2007, more than 120 European and African experts met for the founding workshop of the priority initiative *East Africa: Interdisciplinary and Participatory Research on Interactions between Africa, African Ecosystems, Climate and Societies*, which the Ministry of Foreign Affairs has joined the IRD's Change, At the workshop, participants identified issues common to scientific, decision makers and civil society and picked out the key themes. These will be the focus for calls for projects from IRD/African interdisciplinary teams. Research launch workshops were then held in several other countries of West Africa.

Cooperation in Mozambique took a practical step forward with the signing of a framework agreement with the Mozambique Science and Technology Ministry.

In Mauritania, a partnership agreement was signed with IMMO, the Mauritania Institute of Oceanographic Research and Fisheries.

In Senegal, the IRD and Cheikh Anta Diop University in Dakar held the first "M1" one-day workshops, devoted to the applications of mathematics and informatics to sustainable development issues. These events are helping to structure a high-level scientific community by developing a network of observations in Morocco, Senegal, Cameroon, Vietnam and, soon, South Africa.

In Angola, the IRD and its partner the Angolan Tripartite Science Centre Institute are running a research programme to gain control over African human trypanosomiasis.

## North Africa and Middle East

The strength of our cooperation dynamics in the Mediterranean region was confirmed in Morocco, where new programmes started up with a wider range of partners, universities particularly. The first consultation meeting between the IRD and its Moroccan partner institutions was held in Rabat under the aegis of the Moroccan ministry responsible for research. Also in Rabat, a meeting was held to present the results of the European project *Climate*, which set out to assess the scientific and technological capabilities of eight Mediterranean countries that are partners in European research coordinated by the IRD.

To celebrate fifty years of scientific partnership in Tunisia, the IRD held a seminar under the patronage of the Tunisian research ministry, to present the joint research programmes and the region's development prospects. A new agreement was also signed.

## La tin America

Hydroclimatic programmes in the Andes region continued and some these programmes funded by the French national research agency ANR were set up. These concern a number of fields including climate, seismology, ecosystems, hydrogeology, health environment and migration.

In the programme that is drifting ice cores in the glaciers of Patagonia, a core was taken from the San Valentin glacier for the first time ever.

IRD's National Institute for Space Research (INPE), in partnership with the IRD, organised the 13th Brazilian remote sensing symposium. This symposium provided the opportunity to enhance collaboration on the use of earth observation data for local development.

The IRD and its Peruvian partners celebrated forty years of cooperation. This was also the occasion for signing a tripartite agreement with the Strategic Alliance consisting of San Marcos University, La Molina Agrarian University (UMALM) and the National Engineering University in Lima (UNL).

Mexico and Morocco continued to strengthen their cooperation ties. A programme on the use of satellite data for irrigation management began in Mexico with Moroccan involvement. The IRD and its Moroccan and Mexican partner institutions held a joint seminar in Rabat on "Socio-economic reconversion in face of globalisation and its challenges: a Mexico-Morocco comparative approach". Some forty leading scientific and political figures exchanged views and information on ongoing changes and development prospects, with a view to informing public policy and structuring research networks.

## Asia

Cooperation with Asian organisations developed, particularly on issues related to ecosystems, climate change, infectious diseases and public policy to combat poverty.

The process of structuring research themes region wide based on science platforms took practical shape in Thailand where the technology platform on infectious diseases at Mahidol University was launched. Also in Thailand, and also with a regional remit, work on emerging diseases and zoonotic zoonoses continued.

In Vietnam, a framework agreement with the Vietnamese Academy of Social Sciences was signed and a French science and technology centre opened in Hanoi, in association with the Vietnamese Academy of Science and Technology (CIRAD, CNRS and the Pressur Institute).

In Indonesia, the Centre for International Forestry Research chose the B0 to assist its regional activities in Indonesia and Laos.

## Multilateral cooperation

Multilateral activities continued, primarily through co-operation with the Consultative Group on International Agricultural Research (CGIAR). The B0 is coordinating research on water and poverty in the Niger River Basin for the CGIAR Challenge Programme on water and food.

The B0 worked extensively with partners in the European Consortium for Agricultural Research in the Tropics (ECART) to design international research programmes, mainly concerning desertification control and climate change.

## European cooperation

The B0 is the only research institution in Europe to have so many and such varied competences for world development. It is involved in some forty European projects and maintains relationships with many European scientific institutions. It takes part in institutional coordination projects to enable developing countries to participate in European Union research programmes.

A highlight of 2007 was the 7th Framework Programme for research and development (FP7). For the first calls for proposals, three projects coordinated by the B0 were chosen.

• **Strepcom**, which concerns the effects of pregnancy-associated malaria in Eritrea and West Africa, two endemic malaria regions. The aim is to develop strategies for treatment, prevention and vaccination (7 partners, 6 countries, €3 million).

• **Mede**, which is studying the consequences of pebble fishing and suggesting new methods that will reduce the negative impacts current practices have on some species (13 partners, 6 countries, €3 million).

• **Claris IPE**, which focuses on preventing the impact of climate change in the La Plata basin in South America (20 partners, 10 countries, €3.35 million).

The B0 is a partner in three new bio-led projects designed to achieve better coordination among European Community policies on international scientific cooperation with third countries. These are the coast network with sub-Saharan Africa, the Eurolab project with Latin America and Asia with the Mediterranean countries.

The B0 is also coordinating Europe's regional Contact Point for international cooperation. The purpose of this is to inform French research actors about international cooperation under the FP7, its issues and the opportunities for involving third country partners in EU projects.

Contact\ndne rd.fr

• Farmland - Haut Asia Watersheds.

• North-west of Namay-Niger

The B0 is a member of international cooperation project (AMES) which is coordinated by Alcatel Alenia Space and receives €21 million in funds from the European cooperation and development fund (Eurosaid). The aim of AMES is to help African countries manage their resources better by providing them with much needed data about their environment, obtained using remote sensing from earth observation satellites and other new technologies.

# In the French overseas territories



- Nestlé Innis New Caledonia

The five IRD centres and offices in the French overseas territories provide stable, long term bases for French research in the tropics. They are indispensable for the Institute's own programmes and for national scientific cooperation programmes involving other French institutions. Acting as local development partners and working with the local stakeholders they conduct research in the interests of the region concerned. They also help to develop multilateral relations with neighbouring countries and regions by conducting scientific programmes on shared issues. They can be a particularly precious tool for establishing European research for development.

**In the Irouma centre in New Caledonia** - the Institute's largest overseas centre. It houses 10 units conducting research on a range of issues. In 2007, the funding agreement of the National Research and Technology Centre on Health and the Environment was signed in the presence of the Secretary of State for Overseas Territories. This Centre involves central government, local authorities and the mining industry federation as well as specialists. Its purpose is research on mineral ores and the social, economic and environmental impacts of mining. The scientific partners are CIRAD, the IRSTEA, the IRD and the University of New Caledonia.

The Irouma centre has also been playing a major part in preparing the application to have the coral reefs of New Caledonia listed as Unesco World Heritage. These reefs are an exceptional ecosystem and one of the world's largest and most varied reef systems. In 2007 a set of representative sites, selected mainly on the basis of work by the IRD centre, was put forward for Unesco approval. This decision will be taken in 2008.

**In French Polynesia**, an agreement was signed between the IRD, the University of French Polynesia and the Louis Madaule medical research institute to create a Polynesian centre for research into and commercial use of the islands' biodiversity with a view to giving the three establishments a better competitive edge in the field. The Institute also transferred the Malesiad database and posted it on the Internet (<http://www.biodiversite.fr>). This database covers the specimens of French Polynesia from a French Polynesian herbarium and other major habitats around the world.

**In Martinique**, the Martinique Agro-Environmental Research Centre (PREAM) is effective in bringing together changed. CIRAD and the IRD for research on agriculture and environment. Its work has produced an extensive published output.

- Com'polys'Polynésie

Also from the Martinique centre, the IRD took part in the Sismosites mission, a project to assess geological risks in the Lesser Antilles arc. Its partners are the Paris-based Institut de Physique du Globe, the CNRS, Institut National des Sciences de l'Univers and the volcanological and seismological monitoring systems in Martinique and Guadeloupe.

Under the Carbe-Blycos hydrological monitoring programme the IRD signed four agreements with the local authorities, the Prefecture and the World Meteorological Office.

Visiting research work in **French Guiana** is based on the SEAS stability monitoring station, moved into higher gear and is now achieving international scope through programmes with other countries of the Amazon. Brazil particularly.

The centre in **La Réunion** is now busier than ever and is expanding just. Staff numbers doubled in 2007. CIRAD, the centre for research and surveillance on emerging diseases in the Indian Ocean, was set up as a 66 scientific interest grouping with the IRD as representative. The centre's scientific strategy was defined at the first meeting of its scientific council. Its first call for tenders on emerging infectious diseases transmitted by arthropod vectors in the Indian Ocean region was launched in association with IRD, the CIRAD and the French Health Institute held a symposium on "Chikungunya and other arboviral diseases emerging in tropical environments" in Saint-Denis, La Réunion.

- Centre\Nestlé\Com'polys'

# In Metropolitan France

Competitiveness clusters are another context for applying the partnership approach. It presents the IRD as a member of two competitiveness clusters with global ambitions: Mer-PACA and Mer-Sudpaca, and four with national ambitions: G7-11-Mediterranean in the Languedoc-Roussillon region, Esquisse and Opération in the PACA region and Qualitopac in La Réunion.

## Vocational multi-training programmes

The IRD is also involved in multi-training programmes (PPIs) in which several universities of PACA team up to acquire training resources, mainly equipment. In the overseas territories, they enable teams to come together and structure their research around a topic. The IRD was already a member of three PPIs – one with La Réunion University and two with the University of New Caledonia: those concern "knowledge engineering for integrated management of tropical island coastal areas" and "functional biodiversity, alterations and transfers in ecosystems. From the island basins to the lagoons of New Caledonia". The third, with the University of Toulon, is on "biotechnology, natural substances, uses and optimisation for society".

These projects fall within the priority areas of the IRD's objectives contract and consolidate its partnerships with universities in the overseas territories.

## Project contracts between central and regional government

Scale-Region project contracts (CPRs) were instituted in 2006 to balance major projects over several years, usually for infrastructure or real estate operations. The Institute took part in preparing the 2007-2013 CPRs and is now involved

The Institute strengthened its links with French higher education and research establishments. It increased its involvement in joint research units and continued to join the regional structures created in 2005 under the recent research scheduling and guidelines law.

The IRD's newly streamlined research structure comprises 72 units\*, of which 38 are joint research units (UMRs) with other research establishments. 27 are partly IRD research units and 7 are service units, with nine newly created UMAs, the proportion of joint units has risen from 38% of the total to 53%.

Units with higher education establishments were also consolidated by the Institute's participation in various inter-establishment structures. For example, it took part in setting up the Institute research institute intersite to enable a molecule in the Provence-Alpes-Côte d'Azur region. All in all, the Institute is a member of 10 European research institutes (IFE), 20 scientific interest consortiums (RIS), 7 public interest consortiums (RIPs) and 1 economic interest consortiums (RIEs).

## Involvement in regional structures

The French government recently established a number of regional research structures: thematic networks for advanced research (RTAN), research and higher education clusters (PRES) and "thematic centres for research and treatment" (CET). These structures enable the IRD and partner institutes to work together on extremely high-powered science projects.

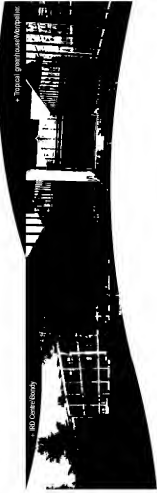
The IRD is a founder member of the following:

- the Aerospace Science and Engineering RTAN in Toulouse, alongside the Université de Toulouse PRES, the CNRS, ONERA and the Association Tonnerre;
- the Agency and Sustainable Development RTAN in Montpellier with CNRS, MIRA and Montpellier SupAgro;
- the Emerging Infectious Diseases and Tropical Diseases in the 21st century CRTS in the Provence-Alpes-Côte d'Azur region, with the Universities of Montpellier 1 and 2, Aix-Marseille 2 and Nice Sophia Antipolis, the CHRS, INSERM, Assistance Publique - Hôpital de Marseille, the Montpellier and Nice teaching hospital groups and the Facultés de Médecine de Montpellier and Nice;
- the IRD is an associate member of the Paris School of Economics RIRL.

\* 31 January 2012

In some fifteen inter-establishment, investment, projects and technology platforms in Languedoc-Roussillon, PACA, Rhône-Alpes, Guyane, May-Pyrenées and La Réunion.

Contact: [rd@ird.fr](mailto:rd@ird.fr)







# RESOURCES for research



# Pooled research equipment available

**Observing and modelling the global environment, or conducting research in biology and medicine demand cutting-edge, high technology equipment. To make this necessary facilities available to its researchers, the IRD has long applied the principle of pooling resources with its partners. For 2007, the IRD spent €1.7 million on financing large-scale equipment, and €1.05 million on modernising its fleet. Networking and extending the accommodation block of the Institute's Ile-de-France centre accounted for most of the expenditure on major building work.**

## Accommodation block at the Ile-de-France IRD centre

To build the Southern countries' research capacity, the IRD takes some hundred doctoral students into its Ile-de-France centre in both each year. The 1,500 m<sup>2</sup> accommodation block, now fully rededicated and up to standard, has 22 bedrooms for young visiting researchers. The building dates from 1952 and has been renovated throughout, with financial help from the Ile-de-France Regional Council and the Seine-Saint-Denis department General Council.

+ Accommodation block Bondy



+ The Atlas



## VOceanographic survey fleet

With resources, equipment renewal and improvements, 2007 was a year of great change for the IRD's flagship fleet. The 115-foot catamaran *Atlas* took sea again after having her engines completely replaced. She spent more than half her 200 days at sea doing scientific work as part of six different surveys, including the 30 and 50 (GE) surveys for the IANIGLA National Mission analysis programme. The task was to study ocean circulation and its variability in the Eastern Atlantic and Gulf of Guinea, and their connections with the climate in neighbouring regions.

The 32-foot motorboat *Als* spent a total of 174 days working on seven scientific surveys in 2007. This included taking measurements for the Arc-Vannu programme on the systemic cycle and empire dynamics of the Vannu subduction zone) and the COBALCOAL survey (study of New Caledonian lagoons, algae and corals).

## VClinical research platforms for HIV/AIDS and vector-borne diseases, Thailand

Preventing transmission of the AIDS virus from mother to infant and treating infected persons are the main goals of International Unit 174 and its clinical research platform in Chiang Mai, Thailand. In partnership with some fifty

hospitals, the HIV prevention and response programme designs clinical experimentation protocols, sponsors procedures, makes thousands of patients over several years and ensures that the risk run smoothly. Alongside the researchers, some hundred Thai research engineers and technicians manage the network of hospital laboratories involved in the research, supervise trials in different locations, carry out laboratory analyses at Chiang Mai University and provide the logistics for treatments from the drug distribution centre. The platform also includes a large training and administrative support group, and processes specially designed for its requirements in collecting, tracking and processing the data on each patient.

The multidisciplinary technical platform on vector-borne diseases at Mahidol University in Bangkok is now operational. It has over 1,200 m<sup>2</sup> of laboratory space equipped for vector entomology, molecular biology and data processing for research on bird flu, zoonoses and viral encephalitis. A high security laboratory is planned for 2008.

+ Chiang Mai platform Thailand



# to partners

## \The Cayenne and Noumea herbaria

In the study of plant resources a herbarium is a vital tool for identifying new plant species and making advances in taxonomy or in understanding the ecology of a species, its distribution or its degree of rarity.

The Cayenne herbarium possesses 160,000 specimens of 5,000 or 6,000 different species from in French Guiana. In 2007 about a thousand more samples were added. The Noumea collection includes 75,000 specimens. In the long run, this herbarium is due to be handed over to the local authorities.

The Cayenne herbarium has already been largely computerised, and its data can be accessed via the Web through a geographical information system. In 2007 more than a thousand new entries and photos were added to the Malakoff database. Now the digitisation of the Noumea collection is under way.

## \Tropical greenhouses in Montpellier

The 2,000 m<sup>2</sup> of tropical greenhouses at the Montpellier centre are divided as a 'grand experiment: *Conservatoire*'. Four families of important crops for Southern countries are tried there: rice, cotton, oil palm and 'bio' tobacco. Bananas, rice and artichokes are tried as plant models for experiments. The greenhouses are used to experiment on genetically modified species, to study how particular genes

are expressed. Once the scientists know what genes or genes are involved in a feature that is considered useful, varieties with that feature can be bred in the field, by conventional means, with no need for artificial genetic modification. To prevent any genetic material leaving the greenhouses, access is restricted by three levels of confinement.

## \A research and monitoring centre for emerging diseases in the Indian Ocean

In its Agency capacity, the IRD is mandated by the scientific interest partnership *Centre de recherche de la santé sur les maladies émergentes dans l'océan indien* to coordinate the call for projects on emerging infectious diseases transmitted by arthropod vectors in the Indian Ocean region. The aim is to set up and run a scientific research and surveillance network. The work involves monitoring emerging infectious diseases (in partnership with the national health and public health authorities of the countries concerned), developing and evaluating innovative public health surveillance methods, and setting up new research programmes structured through regional networks.

## \SeasNet: satellite-aided environmental monitoring

With its long experience of satellite data – interpreting and exploiting them, making them available – the IRD is a partner in the SeasNet programme, which is collecting, analysing and modelling data on the global environment. The network includes three IRD stations, in La Réunion, French Guiana and New Caledonia.

The land and sea data collected are used to study ecosystems (especially deforestation), to monitor water resources and fisheries, and for epidemiological surveillance. The data are fed into environmental information systems, providing experts and decision makers with vital decision aids and environmental management tools.

+ Cayenne herbarium.



+ Van research Montpellier greenhouses.



+ SeasNet satellite receiving station.

# Information systems

The deployment of the information systems master plan continued in 2007.

A Web portal is being formalised as a step forward and making the Sorgho software system accessible to staff. As a first stage, the concerned human resources (non-researcher targeted staff assessments and applications for leave). An information centre makes it easier to use data for management purposes. As a first stage, this concerned mission management.

The scientific computing service offering for researchers and partners continues. In 2007, applied units received support from the Sorgho system. 55 people were trained to use the R statistical tool, an information and information community was organised around tools and methods, and the shared platform Subversion hosted 45 applications. An assessment of the incentive approach shows the advantages it has brought: tools are re-used, technical knowledge shared and transferred, researchers' time freed up.

The computer infrastructure is being allowed to make the system more flexible and better able to meet users' requirements (offering translation, collaboration capability, interoperability) and to ensure that the e-mail system and Sorgho achieve better continuity of service.

Contact: [vd@ipr.fr](mailto:vd@ipr.fr)

# Human resources

This year, arrangements to support staff in the lead-up to moving the IPD's head office to Marseille began, with the opening of an administrative intranet portal and a fresh boost to the Institute's policy on continuing education.

## Staff numbers and parity

The IPD employs 2,235 staff including 630 researchers, 1,007 engineers and technicians and 394 local staff. Their average age (excluding local staff) is 44 (overall, 41). For women and 47 for men (women make up 40-5% of the total).  
- a lower proportion of researchers (24.7%) and senior administrators (40%), but a majority of engineers, technicians and non-tenured staff (57%). A parity committee was set up to assess the place of women in the Institute. It worked out a statistical monitoring system and made proposals to promote professional equality.

## Over 40% of staff work outside France

A particular feature of the IPD is that over 40% of its staff work outside France. In 2007, 916 of its staff overseas, 41% in Africa, 31% in the French overseas territories, 6.5% in Latin America and 4% in Asia. The largest numbers of IPD staff are in Senegal and Burkina Faso for Africa, Brazil, Bolivia and Peru for Latin America, and New Caledonia and French Guiana for the overseas territories. In 2007, staff also went out on 125 long-term missions to strengthen ties abroad.

## Recruitment, mobility and promotion

In 2007, the IPD recruited 16 researchers, including 20 women, through external competitive examinations (16 in researcher grade D22, 5 in grade D17 and 22 in grade D20). Most of these recruitments were in the life sciences (13) and earth sciences (12). In 2006 and 2007 recruitment brought in 51 engineers and technicians (41 women and 20 men).  
Internal mobility was especially strong this year, with 117 engineers and technicians posts on offer making 66 for the forthcoming move to the new head office in Marseille.

Seventeen staff were promoted through internal competitive examinations. Other promotions included 34 engineers and technicians who moved to a higher grade within their category and 7 who moved to a higher category.

## Changes in regulations

The law of 2 January 2007 on modernisation of the civil service introduced a number of changes for IPD staff. Mobility is now possible between the three branches of the civil service, and even to non-IPD organisations or employment with a foreign State. The principles governing public employment, departures to the private sector and encouragement of staff making a setup in business have been updated. Staff now also have a right to continuing education throughout their careers. The law also wants to allow staff the system of compensatory bonuses and partial compensation for those who have a working time savings account. Research grants were increased twice.

## Online administrative portals start up

With Sorgho portal, staff can now consult and update their administrative file and arrange their annual leave online. The portal is used to manage administrative operations electronically and simultaneously update the data in the Sorgho system.

## Continuing education

The IPD continued its policy of training staff for new institutional projects. The introduction of the Sorgho software, application of the constitutional law on budget acts, quality management. Special efforts were made on professional risk prevention, hygiene, safety and on training for staff having to switch to a new post in Ile-de-France when the head office moves to Marseille.

## Health and safety

As well as strengthening its 2007-2008 prevention programme, the IPD produced a risk assessment booklet and a handbook on assessment of professional risks. Both these are now online. Restrictions on specific scale steps were drawn up and operational arrangements for scientific diving were strengthened. Acute was taken to limit smoking in the workplace, to ensure that replacement for health reasons functions more smoothly and to improve the reporting system for workplace accidents.

Contact: [vd@ipr.fr](mailto:vd@ipr.fr)

## Staff by category

	TECHNICAL STAFF	NON-TECHNICAL STAFF**	TOTAL
Researchers	811	19	830
Engineers and technicians	282	202	484
Permanent local staff	760	388	1,148
<b>TOTAL</b>	<b>1,660</b>	<b>635</b>	<b>2,295</b>

\*Non-technical categories: including youth, volunteers, grants and local staff

## Staff by gender

	MEM	%	WOMEN	%	TOTAL
Researchers	623	75.1	207	24.9	830
Engineers and technicians	439	43.0	582	57.0	1,021
Permanent local staff	257	69.5	117	30.5	388
<b>TOTAL</b>	<b>1,329</b>	<b>69.5</b>	<b>906</b>	<b>40.5</b>	<b>2,235</b>

## On assignment outside Metropolitan France

	2003*	2004*	2005*	2006**	2007**
Researchers	37%	34%	35%	37%	35%
Engineers and technicians	31%	25%	21%	20%	25%

\*Year 2003: percentage calculated from budgetary posts \*\*Year 2005: percentage calculated from 880 staff members at 31/12/05 (and local staff)

## Numbers of long-term missions

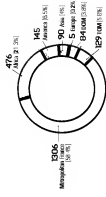
	2002	2003	2004	2005	2006	2007
Africa	15	38	42	60	52	61
America	16	33	45	60	40	36
Asia	4	8	20	32	19	23
Europe	1	2	8	3	6	5
<b>TOTAL</b>	<b>36</b>	<b>81</b>	<b>115</b>	<b>155</b>	<b>117</b>	<b>125</b>

Source: Single Statistics at 31/12/2007

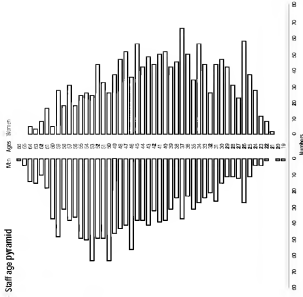
## Researchers by discipline



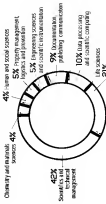
## Staff distribution by region



## Staff age pyramid



## Engineers and technicians by activity branch



# Financial resources

## Sharp increase in own resources

Income from research contracts was €207.5 million, an increase of more than 60% on 2006. This 60% increase was partly due to the launch of the IRD national research agency, but also partly to the IRD's growing role as a research operator for French commissioning bodies (Ministries, public sector bodies) and other partners.

## Active commitment to the new agency's launch

In 2006 the IRD was commissioned to create IRD, the new inter-establishment agency for research for development whose role it is to mobilise all the French research bodies to work for development and coordinate their actions in this regard. In 2007, the IRD embarked a block sum of €6.3 million to get the new agency off the ground and give it the scope to act. This made it possible to mobilise €10 million from external sources for the Agency's priorities.

## Resources for the research and service units

The research and service units directly received €120.6 million – more than 57.5% of the Institute's financial resources. They accounted for over 65.0% of payroll expenses and over 35.1% of the investment and operating budgets. The high level of researcher expenditure is reflected in the €20.42 million allocated under that heading.

## Incentive policy to target scientific priorities

A financing system based on incentive credits for scientific programming was set up for the research and service units. These funds are intended to support operations of strategic scope in line with the objectives contract. They amounted to €11.1 million (including ARD).

## Continued investment in shared capital equipment

The IRD spent €1.74 million to finance major capital equipment items for research. Among the most significant were the following:

- ICI MS high resolution mass spectrometer at the IRD-France Centre;
- jointly financed with the Rhône-Alpes Regional Council, the European Union and the CNRS, a tandem particle accelerator in Marseille;
- joint acquisition with the CNRS of a Zeiss confocal microscope in Montpellier.

On its maritime resources side, modernisation of the fleet continued. The Institute spent €1.06 million to renew scientific equipment on its ocean going ships.

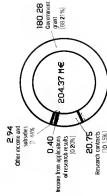
The Institute's €2.80 million in contributions to partnerships highlight the strength of its support for its partners, French and international research bodies.

## Maintaining property assets

The resources allocated to maintenance and major building works amounted to €1.12 million. This work included completion of the extension to the accommodation block at the IRD-France Centre (€1 million), participation in the creation of an oceanography centre under the Europe Aler project in Brest (€0.3 million), and the creation of premises for the insect pest control laboratory in Montpellier (€0.3 million).

Contact'dile led.fr

## IRD Resources (€ million)



The year reflected the Institute's aim of updating its operational framework and focusing its partnerships and research team deployment on research issues of key importance for development, as set out in its 2006-2009 objectives contract. The Institute's own resources increased sharply in 2007 and funds were re-allocated to launch the IRD's programmes (including expertise).

The IRD's budget for 2007 was €220.22 million (vs. €199.43 million in 2006). The balance was provided by research (€20.79 million from the Institute's working capital. The IRD has three sources of funds: government grant (€150.26 million in 2007, or 68.7%), research contract revenue (€20.75 million) and miscellaneous income (€43.34 million). Staff salaries accounted for 71.27% of this budget, €149.52 million.

# Expenditure of research and service units (€ million)

2007 expenditure from government grant and own resources

BY RESEARCH DEPARTMENT	PAYROLL	OPERATING COSTS AND INVESTMENT	TOTAL
Earth and Environment department	31.21	32.83	64.04
Living Resources department	32.76	6.86	39.62
Sciences and Health department	8.37	43.17	51.54
<b>TOTAL</b>	<b>68.79</b>	<b>21.85</b>	<b>120.64</b>

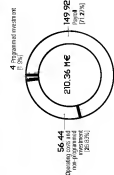
  

BY RESEARCH PROGRAMME	PAYROLL	OPERATING COSTS AND INVESTMENT	TOTAL
Natural hazards, climate and non-renewable resources	6.10	1.44	7.54
Sustainable management of Southern ecosystems	16.46	3.84	20.30
Central and coastal waters	20.39	4.39	24.78
Food security in the South	17.06	3.39	20.44
Health, hygiene and public health policy	16.41	6.01	22.42
Development and globalisation	18.35	2.78	21.14
<b>TOTAL</b>	<b>98.79</b>	<b>21.85</b>	<b>120.64</b>

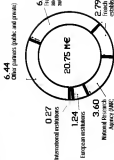
# Expenditure of cross-cutting departments (€ million)

	PAYROLL	OPERATING COSTS AND INVESTMENT	TOTAL
Support and training	0.72	3.53	4.25
Consulting and applications	0.55	0.80	1.35
Scientific information and communication	4.70	1.86	6.56
Informational relations	6.81	3.57	10.38
Scientific outreach	2.28	0.18	2.46
Scientific evaluation, ethics	0.47	0.28	0.75
Continuing education	0.16	1.30	1.46
Contributors to partnerships	0.10	2.69	2.79
Natural resources	0.11	4.27	4.38
Other large-scale scientific equipment		0.75	0.75
TOTAL	17.90	19.24	37.14

# IRD expenditure, by type (€ million)



# Research contract resources, by origin (€ million)



# Expenditure by region (€ million)



# Expenditure of support functions (€ million)

	PAYROLL	OPERATING COSTS AND INVESTMENT	TOTAL
Human resources	0.22	1.13	1.35
Information systems	2.84	5.15	7.99
Research operations	3.19	2.17	5.36
Research services	8.01	5.84	13.85
Other	12.13	4.04	16.17
<b>TOTAL</b>	<b>33.25</b>	<b>10.38</b>	<b>52.63</b>

# Research contract income, by origin (€ million)

	AMOUNT
Earth and Environment department	4.37
Living Resources department	4.55
Sciences and Health department	5.85
Other	4.67
Partners under IRD management*	1.31
<b>TOTAL IN BUDGET</b>	<b>20.75</b>
Paid out to partners of budget	1.70
<b>TOTAL</b>	<b>22.45</b>

\*Naturally valid European and UN contracts, GSC, etc.





# Appendices



\* IRD unit directors and representatives from 2007.

# The IRD's decision bodies

## Board of Trustees (at 1 April 2008)

**Chairman**  
Jean-François Grand

### Ministry representatives:

- **Ministry of Research and Higher Education**  
Dolier Helfrich, adviser to the Directorate General for Research and Innovation
- **Ministry of Education**  
Philippe Mabi, scientific advisor
- **Ministry of Foreign Affairs**  
Antoine Gresson, director of academic, scientific cooperation and research  
Michel Piron, deputy director of development policy

## Scientific council (at 1 May 2008)

**Chair**  
Daniel Le Boulleir, faculty member, University of Aix, microbiology

### Unappointed members

- Jean-Louis Acard, faculty member, university of Clermont-Ferrand, economics
- Najib Ben Mechla, faculty member, National Institute of Agronomy, Tunisia (INAT), agro-climatology
- Fredric Delbecq, research director, CNRS, oceanography
- Stephane Dumas-Bile, faculty member, public law, Jean Monnet university (June 3), international law
- Jacqueline Hanes, faculty member, university of Versailles-St-Quentin-en-Yvelines, sociology
- Nelson Pissinatti, technical adviser to the Ministry of Research, Brazil, design and environment
- Remy Pochet, scientific director, Central Laboratory of Public Works, engineering, evaluations

### ● Budget Ministry

Danièle Chénissou, telecommunications engineer, head of budget management office

### ● Ministry for Overseas Territories

Philippe Luyssens, director for economic, social and cultural affairs in the overseas territories

### At internal members

- Alain Aronow, honorary chair, CNRS
- Catherine Brodignon, chair, CNRS
- Monique Capron, chair, INED
- Patrice Daire, chair, CNRS
- Fred Delbecq, chair, University of Grenoble 1
- Joseph Gaurier, chair, University of Montpellier
- Reine-Marie Gaurier, chair, University of Montpellier
- Adèle Masson, secretary, science faculty, University of Montpellier
- Pierre-Jacques, director of strategy, French Development Agency

### US staff representatives

- Dolier Helfrich, representing STIRN-SEEN-GTFC research staff
- Mireille Chaudry, biologist, representing STIRN-SEEN-GTFC staff
- Alain Pissinatti, doctor of medicine, representing STIRN-SEEN-GTFC staff
- Angèle Girard, documentalist, representing STIRN-SEEN-GTFC staff
- Françoise Martin, secretary, representing STIRN-SEEN-GTFC staff
- Christian Valentin, soil scientist, representing STIRN-SEEN-GTFC research staff

Jean-Luc Reddegar, research director, CNRS, climatology

Sergio Revilla, faculty member, Metropolitan Autonomous University, Mexico, microbiology/hydrobiology

Jean-Pierre Rivest, faculty member, University of Quebec, ecology, environment

Barbara Romanowicz, faculty member, University of Berkeley USA, geophysics

Marcelo Sarmiento, faculty member, University of Berkeley USA, parasitology

Radouane Spachetti, faculty member, University of Geneva and Director of the Geneva Botanical Gardens, biology and plant ecology

Atlected members

- **College 1: RD research directors**  
Jean-Albert, hydrology  
Jean-Claude, hydrology  
Gilles de Noy, geography, research management  
Jean-Paul Gaudet, urban ecology  
Emmanuel Gaudet, geography  
Michel Thévenaz, genetics of infectious diseases

- **College 2: RD researchers**  
Sylvain Bonnard, geophysics  
Dominique Bouchet, anthropology of health  
Alain-Hélène Durand, economics  
Michel Petit, remote sensing, hydrobiology  
Yves Gaudet, anthropology  
Yann Moreau, hydrobiology

### ● College 3: RD engineers and technicians

- Olivier Fossat, hydrobiology  
Yann Hély, geophysics  
Michel Lanté, research management, IRD representative in Indonesia

## Scientific commissions

Chairs of national scientific commissions (CNRS) and research and applications management commissions (CIRA)

- Brigitte Jamin, CNRS 1: physics and chemistry of the planetary environment
- Yves Luyssens, CNRS 2: biology and medical sciences
- Raymond Lue, CNRS 3: sciences of ecological systems
- Catherine Aubertin, CNRS 4: human and social sciences
- Françoise Gaudet, CNRS 5: engineering and consulting
- Hervé de Trancart, CNRS 6: administration and management

# Central services

of 1 July 2008



**Jean-François Girard**  
Chairman



**Michel Lacombe**  
Director General



**Vincent Desloges**  
Sponsoring General



**Pierre Soller**  
Erm and environment dept.



**Bernard Doyelle**  
Living resources dept.



**Jacques Charnier**  
Statistics and health dept.



**Günther Helms**  
Company building support



**Stéphane Roud**  
Company and industrial liaison



**Mirko Napoli Faurer**  
Innovation and communication



**Hervé Michel**  
Finance



**Annie-Marie Ingou**  
Personnel



**Daniel Leclerc**  
International relations



**Christian Malton**  
Information technology and digital media



**Benoît Loubout**  
Exhibitions and visitors



**Gilles Porcett**  
Human resources



**Hortense Abadie-Renaud**  
Legal affairs



**Christian Altamir**  
Real estate administration



**Luc Mesquada**  
Accounting affairs

# Research units and service units

<p>● <b>BOURGUET Denis</b> [RD Unit 022] UMR 0609 Centre for population biology and management design/management www.univ-poitiers.fr/~dbourguet</p>	<p>● <b>CHARBIT Yves</b> [RD Unit 108] UMR 0610 Centre for population and development yves.charbit@univ-poitiers.fr www.univ-poitiers.fr/~ycharbit</p>	<p>● <b>CHARVAT Philippe</b> [RD Unit 002] UMR 0609 Centre for population biology and management philippe.charvat@univ-poitiers.fr www.univ-poitiers.fr/~pcharvat</p>	<p>● <b>CHAVANCE Pierre</b> [RD Unit 007] US GERS Managing and reforming systems for tropical forests pierre.chavance@univ-poitiers.fr www.univ-poitiers.fr/~pchavance</p>	<p>● <b>CHENORKIAN Robert</b> [RD Unit 181] UMR 0609 Centre for population and development robert.chenorkian@univ-poitiers.fr www.univ-poitiers.fr/~rchenork</p>	<p>● <b>CHOYE Jean-Luc</b> [RD Unit 178] UMR 0609 Centre for population biology and management choye.jean-luc@univ-poitiers.fr www.univ-poitiers.fr/~jchoye</p>	<p>● <b>CORBER-SALEM Marie-Christine</b> [RD Unit 200] UMR 0609 Centre for population and development marie-christine.corber-salem@univ-poitiers.fr www.univ-poitiers.fr/~mcsalem</p>	<p>● <b>COT Michel</b> [RD Unit 010] UMR 0609 Centre for population biology and management michel.cot@univ-poitiers.fr www.univ-poitiers.fr/~michelcot</p>
<p>● <b>AGIER Michel</b> [RD Unit 196] UMR 0609 Centre for population biology and management michel.agier@univ-poitiers.fr www.univ-poitiers.fr/~magier</p>	<p>● <b>ARDUIN Pascal</b> [RD Unit 000] US 342 Ecological, epidemiological and environmental monitoring pascal.arduin@univ-poitiers.fr www.univ-poitiers.fr/~pardenard</p>	<p>● <b>ARFI Robert</b> [RD Unit 171] UMR 0609 Centre for population and development robert.arfi@univ-poitiers.fr www.univ-poitiers.fr/~rbarfi</p>	<p>● <b>AUGER Pierre</b> [RD Unit 018] US 342 Ecological, epidemiological and environmental monitoring pierre.auger@univ-poitiers.fr www.univ-poitiers.fr/~pauger</p>	<p>● <b>BARTHELEMY Daniel</b> [RD Unit 123] UMR 0609 Centre for population biology and management daniel.barthelemy@univ-poitiers.fr www.univ-poitiers.fr/~dbarthelemy</p>	<p>● <b>BERGER Jacques</b> [RD Unit 008] UMR 0609 Centre for population and development jacques.berger@univ-poitiers.fr www.univ-poitiers.fr/~jberger</p>	<p>● <b>BOTERO Jean-Yves</b> [RD Unit 100] UMR 0609 Centre for population and development jean-yves.botero@univ-poitiers.fr www.univ-poitiers.fr/~jbotero</p>	<p>● <b>BOUQUET Denis</b> [RD Unit 022] UMR 0609 Centre for population biology and management denis.bouquet@univ-poitiers.fr www.univ-poitiers.fr/~dbouquet</p>

<p>● <b>COTTON Fabrice</b> [RD Unit 177] UMR 0609 Centre for population biology and management fabrice.cotton@univ-poitiers.fr www.univ-poitiers.fr/~fcotton</p>	<p>● <b>COURET Dominique</b> [RD Unit 020] UMR 0609 Centre for population and development dominique.couret@univ-poitiers.fr www.univ-poitiers.fr/~dcouret</p>	<p>● <b>CUNY Gérard</b> [RD Unit 177] UMR 0609 Centre for population biology and management gerard.cuny@univ-poitiers.fr www.univ-poitiers.fr/~gcuny</p>	<p>● <b>DE LAUBALLIERE Xavier</b> [RD Unit 180] UMR 0609 Centre for population and development xavier.de-lauballiere@univ-poitiers.fr www.univ-poitiers.fr/~xlauballiere</p>	<p>● <b>DELAPORTE Éric</b> [RD Unit 145] UMR 0609 Centre for population and development eric.delaporte@univ-poitiers.fr www.univ-poitiers.fr/~edelaporte</p>	<p>● <b>DREYFUS Bernard</b> [RD Unit 145] UMR 0609 Centre for population and development bernard.dreyfus@univ-poitiers.fr www.univ-poitiers.fr/~bdreyfus</p>	<p>● <b>DU PENHOAT Yves</b> [RD Unit 265] UMR 0609 Centre for population and development yves.dupenhoat@univ-poitiers.fr www.univ-poitiers.fr/~ydupenhoat</p>	<p>● <b>ECHEVERRIA Manuel</b> [RD Unit 121] UMR 0609 Centre for population and development manuel.echeverria@univ-poitiers.fr www.univ-poitiers.fr/~mecheverria</p>
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<p>● <b>EYMAUD Laurence</b> [RD Unit 127] UMR 0609 Centre for population biology and management laurence.eyraud@univ-poitiers.fr www.univ-poitiers.fr/~leyraud</p>	<p>● <b>FAURE Yves-André</b> [RD Unit 028] UMR 0609 Centre for population and development yves-andre.faure@univ-poitiers.fr www.univ-poitiers.fr/~yfaure</p>	<p>● <b>FERRARIS Jocelyne</b> [RD Unit 128] UMR 0609 Centre for population and development jocelyne.ferraris@univ-poitiers.fr www.univ-poitiers.fr/~jferraris</p>	<p>● <b>FICHEZ Renaud</b> [RD Unit 135] UMR 0609 Centre for population and development renaud.fichez@univ-poitiers.fr www.univ-poitiers.fr/~rfichez</p>	<p>● <b>FONTENILLE Didier</b> [RD Unit 016] UMR 0609 Centre for population and development didier.fontenille@univ-poitiers.fr www.univ-poitiers.fr/~dfontenille</p>	<p>● <b>FRON Pierre</b> [RD Unit 091] UMR 0609 Centre for population and development pierre.fron@univ-poitiers.fr www.univ-poitiers.fr/~pfron</p>	<p>● <b>GARIN Patricia</b> [RD Unit 183] UMR 0609 Centre for population and development patricia.garin@univ-poitiers.fr www.univ-poitiers.fr/~pgarin</p>	<p>● <b>GOURIQUO Yves</b> [RD Unit 191] UMR 0609 Centre for population and development yves.gouriquo@univ-poitiers.fr www.univ-poitiers.fr/~ygouriquo</p>	<p>● <b>GUICHOUA André</b> [RD Unit 207] UMR 0609 Centre for population and development andre.guichoua@univ-poitiers.fr www.univ-poitiers.fr/~aguichoua</p>
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<p>● <b>HAMON Serge</b> [30 unit 148] UMR 0476 Diversity and adaptation of cultivated plants serge.hamon@ird.fr</p>	<p>● <b>HERBERA-Jovier</b> [30 unit 247] IRD, Development, evolution and long-term analyses herbera@ird.fr</p>	<p>● <b>HUYNTH Frédéric</b> [30 unit 142] USFSPACE: Spatialization of environmental data, research and consulting frédéric.huynt@ird.fr</p>	<p>● <b>JOUVET Marie-Josée</b> [30 unit 107] IRD, OM: identity construction and globalisation marie-josée.jouvet@ird.fr</p>	<p>● <b>JOSSE Erwan</b> [30 unit 004] USMORUELA: life-go-socials: applied to fishery and aquatic ecology and ecology erwan.josse@ird.fr</p>	<p>● <b>KEER Yann</b> [30 unit 113] UMR 0580: Vectors for the study of the biosphere from space yann.keer@ird.fr</p>	<p>● <b>LAE Raymond</b> [30 unit 072] IRD, BIO: The responses of fish stocks and populations to environmental pressures raymond.lae@ird.fr</p>	<p>● <b>LALEMAN Marc</b> [30 unit 174] IRD, RD: - PFT: Clinical applications, mother and infant health and IT in Sustainable marc.laleman@ird.fr</p>	<p>● <b>LALOU Richard</b> [30 unit 151] UMR 1840: Population-environment-development laboratory richard.lalou@ird.fr</p>	<p>● <b>LANGUE Marie-France</b> [30 unit 026] IRD, BIO: The evolution of the marie-france.langue@ird.fr</p>
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<p>● <b>LAVELLE Patrick</b> [30 unit 137] UMR 0504: Soil functioning and biodiversity patrick.lavelle@ird.fr</p>	<p>● <b>LEBEL Thierry</b> [30 unit 073] UMR 111: Laboratory for the study of transfers in hydrology and environment thierry.lebel@ird.fr</p>	<p>● <b>LEDRU Marie-Françoise</b> [30 unit 032] IRD, RD: 1.4: Values and life-style: water resources - management and policies marie-françoise.ledru@ird.fr</p>	<p>● <b>LEGENDRE Marc</b> [30 unit 115] IRD, GVAR: Characterization and utilization of fish diversity for integrated aquaculture marc.legendre@ird.fr</p>	<p>● <b>LE GUIVADER Hervé</b> [30 unit 146] UMR 516: Systems, adaptation, evolution herve.le-guivader@univ-st-etienne.fr</p>	<p>● <b>LIQUORNE Jean-Paul</b> [30 unit 028] IRD, GEA: Climate, silviculture agrobiosphère et stabilisation production jean-paul.liquorne@ird.fr</p>	<p>● <b>MARSAC Francis</b> [30 unit 109] IRD, RE: The impact of biological invasions Francis.marsac@ird.fr</p>	<p>● <b>MEMERY Laurent</b> [30 unit 156] UMR 0505: Marine environment sciences laboratory laurent.memery@univ-brest.fr</p>	<p>● <b>MICHON Geneviève</b> [30 unit 193] IRD: Eco-cybernetics: dynamics and resource management genevieve.michon@ird.fr</p>	<p>● <b>MOATI Jean-Paul</b> [30 unit 012] UMR 015: The dynamics of forests, health systems, societies moati@ird.fr</p>
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<p>● <b>MONTEL Jean-Marc</b> [30 unit 154] UMR 1162: Laboratory for the study of transfer mechanisms in geology jean-marc.mon@ird.fr</p>	<p>● <b>MORETTE Christian</b> [30 unit 036] USBDIVM: knowledge of tropical plant resources and their uses christian.morette@ird.fr</p>	<p>● <b>NEPVEU Françoise</b> [30 unit 127] UMR: Physiological chemistry of natural substances and related phenomena francoise.nepveu@ird.fr</p>	<p>● <b>NICOLE Michel</b> [30 unit 162] UMR 505: The influence of genetic and diseases michel.nicole@ird.fr</p>	<p>● <b>OBEDCOFF Thierry</b> [30 unit 131] IRD, MAINE: Multi-ecological approach to aquatic biodiversity in continental waters thierry.obedcoff@ird.fr</p>	<p>● <b>ORTIEUX Luc</b> [30 unit 055] IRD, PULIDROH: Tropical radio-measurements and climate variability luc.ortieux@ird.fr</p>	<p>● <b>QUEKALOS Francisco</b> [30 unit 134] UMR: The study of indigenous languages of Mexico francisco.quek@ird.fr</p>	<p>● <b>QUENSIERE Jacques</b> [30 unit 043] UMR 0502: Vectors for economics and ethics for environment and development jacques.quensiere@ird.fr</p>	<p>● <b>RAOULT Didier</b> [30 unit 198] UMR 1801: Emerging tropical and infectious diseases research unit didier.raoult@ird.fr</p>	<p>● <b>RENAUD Françoise</b> [30 unit 155] UMR 0505: The dynamics of infectious diseases from molecular to sociological analysis francoise.renaud@ird.fr</p>
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<p>● <b>ROY Claude</b> [30 unit 107] UMR 170: Ocean physics laboratory claude.roy@ird.fr</p>	<p>● <b>SCHIANO Pierre</b> [30 unit 143] UMR: Magazines of oceans: Marine and fisheries laboratory pierre.schiano@ird.fr</p>	<p>● <b>SERVAI Eric</b> [30 unit 152] UMR 15M: Hydrosciences Montpellier eric.servai@ird.fr</p>	<p>● <b>SILVAIN Jean-François</b> [30 unit 072] IRRE: Biodiversity and evolution of plant-responses against complexes jean-francois.silvain@ird.fr</p>	<p>● <b>SMONON Kratien p.l.</b> [30 unit 024] IR: Ecoregions: Epidemiology and prevention environment and effectiveness of intervention kratien.smonon@ird.fr</p>	<p>● <b>TATONI Thierry</b> [30 unit 197] UMR 1801: Multidisciplinary research of Ecology and Palaeontology thierry.tatoni@univ-corse.fr</p>	<p>● <b>THIEB BERNARD</b> [30 unit 076] UMR 1801: Ecological modelling systems and engineering bernard.thieb@ird.fr</p>	<p>● <b>THOLOZAN Jean-Luc</b> [30 unit 180] IR: IMEC: Microbiology and biotechnology in hot environments jean-luc.tholozan@ird.fr</p>	<p>● <b>VALENTIN Christian</b> [30 unit 118] IRD, SO: 1.10: Soil, land use, degradation, evolution christian.valentin@ird.fr</p>	<p>● <b>VOITZ Marc</b> [30 unit 140] UMR 1501: Laboratory for the study of soil agrosystem- agro-ecosystem interactions voitz@ird.fr</p>
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# IRD establishments around the world

**New Caledonia and South Pacific**  
Representative: Fabrice Colin  
RD - BP 65 - 98818 Noumea Cedex  
Tel: 06 97 26 10 00  
fax: 06 97 26 10 00  
cristelle.chelmeier@ird.fr - www.ird.fr

**French Polynesia**  
Representative: Jacques Hls  
RD - BP 529 - 98713 Papeete - Tahiti  
Tel: 06 89 91 62 00  
polyseme@ird.fr

**La Réunion**  
Representative: Jean-Baptiste  
RD - BP 112 - 97492 Sainte-Clotilde cedex  
Tel: +33 2 62 62 29 58 29  
brunocourt@ird.fr

**AFRICA**  
**South Africa, Mozambique**  
Representative: Jean-Marie Ritsch  
RD Agence du Hls - PO Box 592 - Newmarket 2113  
Johannesburg - 16, Margaret Manguela Street  
Tel: (27 11) 839 05 61/64  
marie-dominique@ird.fr

**Benin**  
Representative: Bruno Bédigbe  
RD 05/C - Université de France à Cotonou  
RD - BP 155 - 00133 Cotonou  
Tel: 229 20 30 61 37 39  
benin@ird.fr - www.ird.fr/benin

**Burkina Faso**  
Representative: Jean-Pierre Goussard  
RD - BP 155 - 00133 Cotonou  
Tel: 229 20 30 61 37 39  
burkina-faso@ird.fr - www.ird.fr/burkina

**Cameroon**  
Representative: Jean-Claude  
RD - BP 155 - 00133 Cotonou  
Tel: 229 20 30 61 37 39  
cameroon@ird.fr

**Egypt**  
Representative: Nathalie Bernard Manguela  
RD - BP 26 - 12 211 Giza, Egypte  
Tel: 202 2362 05 30  
egypte@ird.fr - www.ird.fr

**Kenya**  
Representative: Jean-Baptiste  
RD Agence CMI - United Nations Avenue, Giza  
RD Box 28477 - 00100 Nairobi  
Tel: 254 20 722 0150  
kenya@ird.fr - www.ird.fr/kenya

**Mali**  
Representative: Ollivier Fodrine  
RD - BP 2308 - Bamako - Mali  
Tel: 223 20 72 05 01  
mali@ird.fr - www.ird.fr/mali

**Mexico**  
Representative: Henri Gauthier  
RD - BP 8580 - 10000 Mexico City  
Tel: 52 55 21 28 14 64  
mexico@ird.fr - www.ird.fr/mexico

**Niger**  
Representative: Ollivier Bertrandon  
RD - BP 114 B - Niamey  
Tel: 227 20 72 05 01  
niger@ird.fr - www.ird.fr/niger

**Senegal**  
Representative: Christophe Gauthier  
RD - BP 155 - 00133 Cotonou  
Tel: 229 20 30 61 37 39  
senegal@ird.fr - www.ird.fr/senegal

**Tunisia**  
Representative: Jean-Claude  
RD - BP 155 - 00133 Cotonou  
Tel: 229 20 30 61 37 39  
tunisie@ird.fr - www.ird.fr/tunisie

**INDIAN OCEAN**  
Representative: Jean-Baptiste  
RD - BP 155 - 00133 Cotonou  
Tel: 229 20 30 61 37 39  
indian-ocean@ird.fr - www.ird.fr/indian-ocean

**LATIN AMERICA**  
Representative: Jean-Baptiste  
RD - BP 155 - 00133 Cotonou  
Tel: 229 20 30 61 37 39  
latin-america@ird.fr - www.ird.fr/latin-america

**France**  
Representative: Jean-Baptiste  
RD - BP 155 - 00133 Cotonou  
Tel: 229 20 30 61 37 39  
france@ird.fr - www.ird.fr/france

**Guinea**  
Representative: Sébastien Hls  
RD - BP 155 - 00133 Cotonou  
Tel: 229 20 30 61 37 39  
guinea@ird.fr - www.ird.fr/guinea

**Guinea-Bissau**  
Representative: Sébastien Hls  
RD - BP 155 - 00133 Cotonou  
Tel: 229 20 30 61 37 39  
guinea-bissau@ird.fr - www.ird.fr/guinea-bissau

**Madagascar**  
Representative: Sébastien Hls  
RD - BP 155 - 00133 Cotonou  
Tel: 229 20 30 61 37 39  
madagascar@ird.fr - www.ird.fr/madagascar

**Mali**  
Representative: Sébastien Hls  
RD - BP 155 - 00133 Cotonou  
Tel: 229 20 30 61 37 39  
mali@ird.fr - www.ird.fr/mali

**ASIA**  
Representative: Sébastien Hls  
RD - BP 155 - 00133 Cotonou  
Tel: 229 20 30 61 37 39  
asia@ird.fr - www.ird.fr/asia

**Laos**  
Representative: Sébastien Hls  
RD - BP 155 - 00133 Cotonou  
Tel: 229 20 30 61 37 39  
laos@ird.fr - www.ird.fr/laos

**Thailand**  
Representative: Sébastien Hls  
RD - BP 155 - 00133 Cotonou  
Tel: 229 20 30 61 37 39  
thailand@ird.fr - www.ird.fr/thailand

**Vietnam**  
Representative: Sébastien Hls  
RD - BP 155 - 00133 Cotonou  
Tel: 229 20 30 61 37 39  
vietnam@ird.fr - www.ird.fr/vietnam

**EUROPEAN UNION**  
Representative: Sébastien Hls  
RD - BP 155 - 00133 Cotonou  
Tel: 229 20 30 61 37 39  
europa@ird.fr - www.ird.fr/europa

## Annual report 2007

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Institut de recherche  
pour le développement

IRD

213 rue La Fayette  
F-75480 Paris Cedex 10  
Tél. +33 (0)1 46 03 77 77  
Fax +33 (0)1 46 03 08 29

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IRD

SEXTANT

44 Boulevard des Dunkerque  
F-13002 Marseille

[www.ird.fr](http://www.ird.fr)





## Research

## Open Access

### Synergy between repellents and non-pyrethroid insecticides strongly extends the efficacy of treated nets against *Anopheles gambiae*

Cédric Pennetier\*<sup>1,2</sup>, Vincent Corbel<sup>3</sup>, Pélégie Boko<sup>2</sup>, Abibatou Odjo<sup>2</sup>, Raphaël N'Guessan<sup>2,4</sup>, Bruno Lapied<sup>5</sup> and Jean-Marc Hougard<sup>1,2</sup>

Address: <sup>1</sup>Institut de Recherche pour le Développement (IRD), Cotonou, Bénin, <sup>2</sup>Centre de Recherches Entomologiques de Cotonou (CREC), Cotonou, Bénin, <sup>3</sup>Laboratoire de Lutte contre les Insectes Nuisibles (LIN), Institut de Recherche pour le Développement (IRD), Montpellier, France, <sup>4</sup>London School of Hygiene and Tropical Medicine, London, UK and <sup>5</sup>RCIM, UPRES EA 2647, Université d'Angers, F-49045 Angers cedex, France

Email: Cédric Pennetier\* - [Cedric.Pennetier@ird.fr](mailto:Cedric.Pennetier@ird.fr); Vincent Corbel - [vincent.corbel@ird.fr](mailto:vincent.corbel@ird.fr); Pélégie Boko - [belombreeta@yahoo.fr](mailto:belombreeta@yahoo.fr); Abibatou Odjo - [abibatho@yahoo.fr](mailto:abibatho@yahoo.fr); Raphaël N'Guessan - [Raphael.N'Guessan@lshtm.ac.uk](mailto:Raphael.N'Guessan@lshtm.ac.uk); Bruno Lapied - [bruno.lapied@univ-angers.fr](mailto:bruno.lapied@univ-angers.fr); Jean-Marc Hougard - [jean-marc.hougard@ird.fr](mailto:jean-marc.hougard@ird.fr)

\* Corresponding author

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## Abstract

**Background:** To manage the *kdr* pyrethroid-resistance in Anopheline malaria vectors, new compounds or new strategies are urgently needed. Recently, mixing repellents (DEET) and a non-pyrethroid insecticide (propoxur) was shown to be as effective as deltamethrin, a standard pyrethroid, under laboratory conditions, because of a strong synergy between the two compounds. In the present study, the interactions between two repellents (DEET and KBR 3023) and a non-pyrethroid insecticide (pyrimiphos methyl or PM) on netting were investigated. The residual efficacy and the inhibition of blood feeding conferred by these mixtures were assessed against *Anopheles gambiae* mosquitoes.

**Methods:** DEET and KBR 3023 were mixed with pyrimiphos methyl (PM), a organophosphate (OP) insecticide. The performance of mono- and bi-impregnated nets against adult mosquitoes was assessed using a miniaturized, experimental hut system (laboratory tunnel tests) that allows expression of behavioural responses to insecticide, particularly the mortality and blood feeding effects.

**Results:** Both mixtures (PM+DEET and PM+KBR3023) induced 95% mortality for more than two months compared with less than one week for each compound used alone, then reflecting a strong synergy between the repellents and PM. A similar trend was observed with the blood feeding rates, which were significantly lower for the mixtures than for each component alone.

**Conclusion:** Synergistic interactions between organophosphates and repellents may be of great interest for vector control as they may contribute to increase the residual life of impregnated materials and improve the control of pyrethroid-resistance mosquitoes. These results prompt the need to evaluate the efficacy of repellent/non-pyrethroid insecticide mixtures against field populations of *An. gambiae* showing high level of resistance to Ops and pyrethroids.

## Background

Pyrethroid insecticides are currently the only chemicals recommended by World Health Organization Pesticide Scheme (WHOPES) for net impregnation because they show low mammalian toxicity and fast acting properties against mosquitoes [1]. Unfortunately, the knock-down resistance (*kdr*) gene conferring cross resistance to pyrethroids and DDT has become widespread in anopheline mosquitoes in Africa [2-5]. This resistance may represent a threat to the future success of malaria vector control programmes, based on insecticide-treated nets (ITNs) and indoor residual spraying (IRS). At present, there is uncertainty as to whether *kdr* undermines the effectiveness of ITN in areas of high prevalence. While experimental hut trial in Côte d'Ivoire [6] and Benin [6,7] demonstrated a survival advantage of mosquitoes being homozygous for the *kdr* resistance, other comparative trials between resistant and susceptible areas showed no apparent difference in the effectiveness of ITN [6,8,9]. The authors of this paper have previously suggested that resistant mosquitoes were less likely to be irritated by pyrethroid-treated nets than the susceptible and, therefore, alight for longer periods on ITNs and die [10,11]. This hypothesis was further explored by a randomized trial set up in Côte d'Ivoire which confirmed that ITNs remain effective in preventing malaria in areas where *kdr* is prevalent [12].

Despite these controversial views, the reduced irritancy observed with ITNs against *kdr*-resistant mosquitoes represents a serious risk for personal protection. A typical example encountered in Benin was that significantly more individuals of the RS and RR genotypes blood fed in the presence of permethrin-treated nets than the susceptible SS [8]. Although carbamates and organophosphates are regarded as possible alternatives to pyrethroids [13,14], they may prove too hazardous for general use and may also select for insensitive acetylcholinesterase resistance in *An. gambiae* [13,15]. Developing alternative chemicals and/or vector control strategies to maintain an effective control of resistant mosquito populations has, therefore, become a priority.

In recent years, repellents have gained increasing interest in public health for protecting people against malaria vectors [16-18]. DEET has been in use since the 1950s and is considered as the standard product against which all other repellents are measured [19]. Recently other active ingredients, known as IR3535 (ethyl butylacetylaminopropionate), KBR 3023 (Bayer), and PMD (para-menthane-3,8-diol) [19] have been formulated for skin application and showed equal or higher performances than DEET against mosquitoes [20]. Unfortunately, the issue with repellents concerns their short residual life which does not permit a long-term use in public health for personal protection. The application of repellents to fabrics, clothes or nets is a

relatively unexplored topic which has potential benefits in terms of safety and cost as direct contact with the chemicals is reduced and persistence enhanced [21,22]. A recent experimental hut trial conducted in pyrethroid resistant area in Côte d'Ivoire, showed that standard lotions of DEET and IR3535 applied on nets showed similar performances than pyrethroid-treated nets during a 6 weeks period [23]. The observed residual effect of DEET on net is far higher than that observed for skin application (6-8 hours)) [18] but shorter than that observed with standard ITNs.

Particularly promising is the good protection obtained from combined use of repellents on skin and ITN for personal protection in Pakistan [16,17]. This example of integrated vector control shows the gains that can be obtained if interventions are used jointly to cover for any limitation in individual interventions [24]. Another promising concept is to associate on nets a synthetic repellent with a non-pyrethroid insecticide to reconstitute pyrethroid features in terms of excitorepulsion and knock-down effect. In a recent laboratory trial, a combination of propoxur (carbamate) and DEET on filter papers resulted in a synergistic effect which induced strong mortality and KD effect against susceptible and pyrethroid-resistant *Aedes aegypti* mosquitoes [25]. Such strategy may be promising for controlling malaria vectors which are becoming more and more resistant to the knock down and irritant effect of pyrethroids [8,11]. Through laboratory assays (tunnel test), the efficacy and persistence (mortality and blood feeding inhibition) of repellent-organophosphate mixtures on polyester nettings against *An. gambiae*, the main malaria vector in Africa, were investigated.

## Methods

### Biological material

The reference susceptible strain of *An. gambiae* Kisumu was used. This strain, originating from Kenya, has been colonized for many years and is free from any detectable insecticide resistance mechanism.

### Insecticide and repellents

Three formulations, one organophosphate insecticide and two repellents, were evaluated on nets, separately or in mixture. Pirigrain® 250 is an Emulsifiable Concentrate formulation (EC) containing 25% pyrimiphos methyl (PM) and manufactured by Compagnie Générale des Insecticides (CGI, France). KBR 3023 (hydroxyethyl isobutyl piperidine carboxylate) is formulated as a liquid concentrate containing 25% of active ingredient. DEET (diethyl-3-methylbenzamide) is also formulated as a liquid concentrate containing 30% of active ingredient. The two experimental formulations of repellents are designed for clothing application and developed by Osler Company (France).

### Net treatment

Netting samples to be tested in the tunnel apparatus were 75 denier multi-filament polyester, mesh 156, provided by Paluteck<sup>®</sup>, Benin. They were treated alone or in combination at 10 g/m<sup>2</sup> with DEET and KBR 3023 and 150 mg/m<sup>2</sup> with PM. These dosages have been selected after preliminary tests, as the lower dosages inducing 100% mortality in tunnel. Because repellents are volatile compounds, tests under tunnels were carried out near after the impregnation process (6 hours). Then blood-feeding inhibition and mortality were evaluated twice a week until efficacy dropped to values below 30%.

### Study design and statistical analysis

The tunnel system is composed of a square glass cylinder, 25 cm high, 21 cm wide, 60 cm long, with a square of netting sizing 25 × 25 cm with nine 1 cm diameter holes fixed into a frame which slots across the tunnel dividing it into two chambers. In the bait chamber, a guinea pig is housed unconstrained in a cage and provided with food and water, and in the other chamber, 100 unfed female mosquitoes aged 5–8 days are released at dusk and left overnight in the dark. The following morning, the number of mosquitoes found live or dead, fed or unfed in each compartment was recorded.

Blood feeding reduction was assessed by comparing the proportion of blood-fed females (whether they were alive or dead) in treated and control tunnels. With each treatment, the blood feeding inhibition rate (BFI) was calculated using the following formula:

$$BFI = 100 - \frac{(\text{Treated} \times 100)}{\text{Control}} \quad \text{Eq.1}$$

Overall mortality was measured by pooling both immediate (12 hrs) and delayed (24 hrs) mortality of mosquitoes from the two sections of the tunnel. When control mortality exceeded 5%, treatment-induced mortality rates were corrected using the Abbott formula [29]:

$$\text{Corrected Mortality} = \frac{(\text{Treated} - \text{Control})}{(100 - \text{Control})} \quad \text{Eq.2}$$

The Lethal Time (LT) and Biting Inhibition Time (BIT) were afforded by each treatment by fitting a sigmoidal time-response model with GOSA<sup>®</sup> software [26] using the following formula:

$$Y = \min + \frac{(\max - \min)}{1 + 10^{(\log LT_{95} - \log x) \cdot \text{slope}}} \quad \text{Eq.3}$$

where (x) is the time (in days) entered without any transformation (i.e. not in logarithmic form). Y is the response (LT or BIT) which varies between a minimum (min) and

a maximum (max). LT<sub>95</sub> and BIT<sub>95</sub> are respectively the Lethal Time and Biting Inhibition Time (days) for Y 95% mortality or blood feeding between min and max respectively, i.e. the time after which 95% mosquitoes are dead or still unfed. Slope represents the slope of the curve at its midpoint.

In order to detect any synergy between PM and DEET or KBR, the results observed with the two mixtures with those theoretically expected in the absence of any interaction (unrelated joint action) between the two compounds were compared [27]. The expected mortality was calculated by multiplying the survival rates of each compound tested separately at each time class and subtracting the result from 100%, as follow:

$$\text{Exp} = 1 - ((1 - \text{mort}^{\text{PM}}) \times (1 - \text{mort}^{\text{KBR}})) \quad \text{Eq.4}$$

Expected values of mortality and blood feeding inhibition rate were also fitted using the same sigmoidal time-response model. Then observed and expected LT<sub>95</sub> and BIT<sub>95</sub> were compared. There was synergy when the observed results were significantly higher than the expected one. Conversely, there was antagonism when the observed results were significantly lower than the expected one. The differences between two LT<sub>95</sub> and two BIT<sub>95</sub> values were considered as significant if their 95% confidence intervals (CI<sub>95</sub>) did not overlap.

### Results

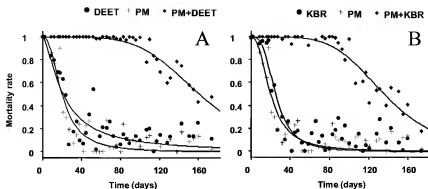
The mortality and blood feeding inhibition rates recorded during the evaluation are shown in Figure 1 and 2. Statistics are summarized in Table.

#### Lethal effect

When freshly treated, mortality of *An. gambiae* was 100% with each type of treatment (singles and mixtures). There was a more rapid decline in activity over time of the mono treatments than the mixtures. At their respective dosage, the LT<sub>95</sub> of each chemical never exceeded 10 days (LT<sub>95</sub><sup>PM</sup> = 5.46 days ± 2.14; LT<sub>95</sub><sup>DEET</sup> = 2.79 days ± 1.68; LT<sub>95</sub><sup>KBR</sup> = 9.43 days ± 3.17). KBR showed a LT<sub>95</sub> similar to PM but significantly longer than DEET. The two mixtures DEET/PM and KBR/PM (Figure 1a and 1b) killed 95% mosquitoes for more than 60 days (LT<sub>95</sub><sup>PM+DEET</sup> = 87 ± 11; LT<sub>95</sub><sup>PM+KBR</sup> = 73 ± 9).

#### Blood feeding inhibition

Onset inhibition of blood feeding was total (100%) with every treatment. The time required to inhibit 95% of the blood feeding (BIT<sub>95</sub>) was three days (± 3), six days (± 3) and eight days (± 5) for PM, DEET and KBR, respectively. There was no significant difference between the three molecules tested (Table 1). PM+DEET mixture induced 95% blood feeding inhibition for more than one month



**Figure 1**  
**Decline with time in treated nets efficacy.** Mortality of *An. gambiae* Kisumu during overnight exposure to treated netting in tunnel test apparatus; Pyrimiphosmethyl was used at 150 mg/m<sup>2</sup> alone and combined with (a) DEET 10 g/m<sup>2</sup> and (b) KBR 10 g/m<sup>2</sup>. Surimposed curves drawn according to sigmoidal time-response model of equation (3) whose parameters are shown in Table 1.

( $BIT_{95}^{PM+DEET} = 37 \pm 10$  days), whereas the effect lasted for three weeks only for the PM+KBR mixtures ( $BIT_{95}^{PM+KBR} = 21 \pm 8$  days). The BIT of the mixtures was significantly longer than those observed when each compound was used separately (Figure 2a and 2b).

### Synergy

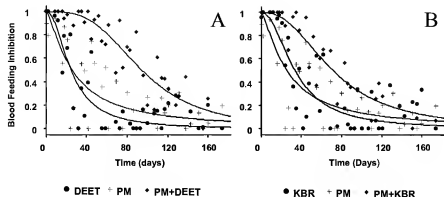
There were highly significant differences between expected and observed  $LT_{95}$  of PM+DEET and PM+KBR (95% CI do not overlap) indicating a strong synergy between PM and the repellents tested in terms of mortality (Table 1). A strong synergy was also noted with blood feeding inhibition, the observed  $BIT_{95}$  of the PM+DEET mixture being significantly greater than expected (Table 1). For the mixture PM+KBR, however, there was no significant difference between expected and observed blood feeding inhibition (overlapping of the confidence intervals), then suggesting a simple additive effect for blood feeding inhibition.

### Discussion

When used separately, DEET and KBR on nets both induced, even for a few days, high mortality rates (more than 95%). This is a confirmation that DEET is not only a behavioural modifying chemical but also a toxicant as previously demonstrated by several authors [23,28-30]. The molecular events involved in DEET toxicity in insects is currently under investigation [31,32]. More surprising was the mortality observed with KBR 3023 in tunnel

apparatus. Indeed, KBR 3023 did not show insecticidal properties as DEET in previous works [30] but it was not tested on impregnated materials. However, the dose of KBR used in previous works (2 g/m<sup>2</sup> on filter papers) as well as the time of exposure (1 h in WHO test kits) was far below the one used in this study (10 g/m<sup>2</sup> and 12 hrs exposure). As far as residual efficacy is concerned, results with DEET are similar to those obtained in tunnel tests by N'Guessan et al. [23] in term of mortality but strongly different in term of blood feeding inhibition (three weeks of total protection vs. four days in this study). This difference may be due to the mosquito species used instead (*Culex quinquefasciatus*) and/or the formulations (DEET in alcohol versus liquid concentrate).

When used in mixtures, results clearly indicate that mixing an OP with a repellent significantly improve, at least under tunnel, the efficacy of nets against anopheline mosquitoes, both in terms of mortality and blood feeding inhibition. This is a confirmation of a previous study that showed a strong synergistic interaction between DEET and propoxur (carbamate) against *A. aegypti* mosquitoes [25]. In this study, thanks to synergy, it appears that a mixture combining an organophosphate insecticide with a repellent (DEET or KBR3023), is as effective as a most pyrethroids recommended by WHO for the treatment of mosquito nets [33]. Indeed, the overall efficacy of the mixtures was maintained for more than four months with PM+KBR3023 and five months PM+DEET in tunnel tests.



**Figure 2**  
Decline with time in blood feeding inhibition. Blood feeding inhibition provided by treated netting against *An. gambiae* Kisumu during overnight tests in tunnel test apparatus; Pyrimiphos-methyl was used at 150 mg/m<sup>2</sup> alone and combined with (a) DEET 10 g/m<sup>2</sup> and (b) KBR 10 g/m<sup>2</sup>. Surimposed curves drawn according to sigmoidal time – response model of equation (3) whose parameters are shown in Table 1.

Moreover, the tested mixture showed a residual effect longer than the one observed by other authors with chlorpyrifos-methyl (one month at 100 mg/m<sup>2</sup>) (N'Guessan personal communication) and approximately similar to the one observed with PM alone (7 months versus 5 in our study) [34]. However, the dosage used was very high (1,000 mg/m<sup>2</sup>) compared to 150 mg/m<sup>2</sup> in the present study.

The great efficacy of these two repellent/OPs mixtures may offer interesting prospects for controlling malaria vectors.

It could be a promising strategy to manage *kdr*-resistant mosquitoes [25], since the non-pyrethroid mixture on net seems to be as effective as a pyrethroid insecticide. Another advantage is the considerable reduction of the insecticide amount on net, therefore, pledging the use of OPs on net. Next steps will consist in evaluating the efficacy and residual activity of these mixtures in experimental huts in the field. It would be also interesting to investigate the effectiveness of such mixtures against mosquitoes bearing other resistance mechanisms, such as the insensitive acetylcholine esterase (AChE<sup>R</sup>) [35].

**Table 1: Summary statistics for nets treated with Pyrimiphos-methyl (PM 150 mg/m<sup>2</sup>), DEET and KBR (both at 10 g/m<sup>2</sup>), alone and in combination against susceptible *An. gambiae*. Slope (95% CI), Lethal Time for 50 and 95% (LT<sub>50-95</sub> in days), Biting Inhibition Time 50 and 95% (BIT<sub>50-95</sub> in days).**

Insecticide/repellent	Mortality						Blood Feeding Inhibition					
	slope	(95%CI)	LT <sub>50</sub>	(95%CI)	LT <sub>95</sub>	(95%CI)	slope	(95%CI)	BIT <sub>50</sub>	(95%CI)	BIT <sub>95</sub>	(95%CI)
PM	-2.29 <sup>a</sup>	± 0.64	19.67 <sup>a</sup>	± 2.97	5.46 <sup>a</sup>	± 2.14	-1.33 <sup>a</sup>	± 0.59	25.46 <sup>a</sup>	± 9.33	2.80 <sup>a</sup>	± 2.93
DEET	-1.46 <sup>a</sup>	± 0.40	20.91 <sup>a</sup>	± 4.75	2.79 <sup>a</sup>	± 1.68	-2.04 <sup>a</sup>	± 0.78	24.38 <sup>a</sup>	± 5.27	5.79 <sup>a</sup>	± 3.44
KBR	-3.04 <sup>a</sup>	± 0.96	24.79 <sup>a</sup>	± 3.19	9.43 <sup>a</sup>	± 3.17	-2.06 <sup>a</sup>	± 0.81	33.51 <sup>a</sup>	± 7.39	8.03 <sup>a</sup>	± 4.84
PM+DEET	-4.81 <sup>c</sup>	± 0.92	161.03 <sup>b</sup>	± 6.63	87.32 <sup>c</sup>	± 10.84	-3.18 <sup>b</sup>	± 0.90	94.34 <sup>b</sup>	± 7.99	37.44 <sup>b</sup>	± 10.29
PM+DEET expected	-1.37 <sup>a</sup>	± 0.44	31.14 <sup>c</sup>	± 7.56	3.65 <sup>a</sup>	± 2.66	-1.57 <sup>a</sup>	± 0.60	52.46 <sup>b</sup>	± 12.04	8.09 <sup>a</sup>	± 6.11
PM+KBR	-4.79 <sup>c</sup>	± 0.96	135.39 <sup>b</sup>	± 5.22	73.30 <sup>c</sup>	± 9.48	-2.40 <sup>b</sup>	± 0.67	71.42 <sup>b</sup>	± 8.10	21.04 <sup>b</sup>	± 7.54
PM+KBR expected	-1.70 <sup>a</sup>	± 0.54	30.45 <sup>c</sup>	± 6.57	5.41 <sup>a</sup>	± 3.19	-1.74 <sup>a</sup>	± 0.59	58.09 <sup>b</sup>	± 10.72	10.79 <sup>a</sup>	± 6.45

Numbers in the same line sharing the same superscript letter do not differ significantly (Confidence Intervals are overlapping)

## Competing interests

The author(s) declare that they have no competing interests.

## Authors' contributions

CP carried out the laboratory evaluation, analyzed and interpreted data and drafted the manuscript. VC substantially helped draft the manuscript. PB and AO helped to carry out the laboratory evaluation. RN helped draft the manuscript. BL participated to design the study. JMHI designed the study, interpreted the data and helped draft the manuscript.

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## Synergy between insecticide and repellent to combat malaria-carrying mosquitoes

January 2007



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Test de dépistage du goute  
épaisse pour détecter le  
paludisme

### • Departement:

With 40% of the world's population, mainly in the poorest countries, exposed to malaria risk and over 500 million people falling ill with the disease each year, it is still the most worrying tropical parasite disease. Most deaths from malaria occur in sub-Saharan Africa and most of those who die are young children or pregnant women. Although the World Health Organisation strongly recommends the use of mosquito nets impregnated with insecticides such as pyrethroids, the development of resistance to these chemicals has prompted IRD researchers to develop new products that harness synergy between insecticides and repellents.

To protect populations against *Anopheles gambiae*, the principal vector of human malaria in Africa, the World Health Organisation recommends the use of mosquito nets impregnated with insecticides of the pyrethroid family. These chemicals are not very toxic for humans or mammals and can be effective against mosquitoes at very low doses by combining several effects. They are toxic, killing the insect or knocking it out as soon as it touches the net. They are also repellent, limiting the numbers of mosquitoes that enter a bedroom. And they are irritant, so preventing the insect from biting through the mesh of the net. However, excessive or inappropriate use of these products has led to a worrying increase in the numbers of resistant mosquitoes and the risk that the impregnated nets will lose their efficacy.

As there are few replacement insecticides, IRD scientists in collaboration with their Benin and Burkina partners combined a non-pyrethroid insecticide with a repellent in order to reproduce the same properties as the pyrethroids without using those chemicals themselves. A strong synergy was found between insecticides and repellents, the combination proving far more effective than the sum of their respective properties. Further, the efficacy lasted several weeks longer than with each chemical on its own. The combination proved especially advantageous because it can be used for impregnation at far lower doses than the pyrethroids to achieve the same effectiveness.

Industry is beginning to express interest in this synergy concept, developing micro-capsule formulations with repellents and insecticides and experimenting with long-lasting impregnation. Alongside these field studies, laboratory research is trying to improve understanding of the action of the repellents and insecticides on the mosquito's central nervous system and the mechanisms involved in the synergy.

Thematic: Health

Country: Angola, Archipelago of the Canaries, Benin, Burkina Faso, Cameroon, Cape Verde, Central Africa, Congo, Ivory Coast, Gabon, Gambia, Ghana, Guinea, Equatorial Guinea, Guinea-Bissau, Mali, Mauritania, Niger, Nigeria, Democratic republic of Congo, Senegal, Chad, Togo

### For further

Scientific contact  
Jean-Marc Hougaard

### Note

The IRD's website is partially translated into English. Find more information in the French pages of the website [www.ird.fr](http://www.ird.fr)

• Crédits IRD update 08 March 2011

## WHO recommended insecticides for indoor residual spraying against malaria vectors

Insecticide compounds and formulations (1)	Class group (2)	Dosage (g a.i./m <sup>2</sup> )	Mode of action	Duration of effective action (months)
<i>DDT WP</i>	OC	1-2	contact	>6
<i>Malathion WP</i>	OP	2	contact	2-3
<i>Fenitrothion WP</i>	OP	2	contact & airborne	3-6
<i>Phosphor-methyl WP &amp; EC</i>	OP	1-2	contact & airborne	2-3
<i>Bendiocarb WP</i>	C	0.1-0.4	contact & airborne	2-6
<i>Propoxur WP</i>	C	1-2	contact & airborne	3-6
<i>Alpha-cypermethrin WP &amp; SC</i>	P	0.02-0.03	contact	4-6
<i>Bifenthrin</i>	P	0.025-0.05	contact	3-6
<i>Cyfluthrin WP</i>	P	0.02-0.05	contact	3-6
<i>Deltamethrin WP, WG</i>	P	0.02-0.025	contact	3-6
<i>Etofenprox WP</i>	P	0.1-0.3	contact	3-6
<i>Lambda-cyhalothrin WP, CS</i>	P	0.02-0.03	contact	3-6

(1) CS: capsule suspension; EC = emulsifiable concentrate; WP = wettable powder.

(2) OC= Organochlorines; OP= Organophosphates; C= Carbamates; P= Pyrethroids.

**Note:** WHO recommendations on the use of pesticides in public health are valid ONLY if linked to WHO specifications for their quality control. WHO specifications for public health pesticides are available on the WHO homepage on the Internet at <http://www.who.int/whopes/quality/en/>.

## COMBINATION OF A NON-PYRETHROID INSECTICIDE AND A REPELLENT: A NEW APPROACH FOR CONTROLLING KNOCKDOWN-RESISTANT MOSQUITOES

CEDRIC PENNETIER, VINCENT CORBEL, AND JEAN-MARC HOUGARD

Laboratoire de Lutte contre les Insectes Nuisibles, Institut de Recherche pour le Développement, Montpellier, France;  
Centre Institut de Recherche pour le Développement du Bénin, Cotonou, Bénin

**Abstract.** Although pyrethroid-treated materials are a promising tool for the prevention and the control of dengue in the tropics, the development of pyrethroid resistance in the main mosquito vector (*Aedes aegypti*) may negate their use for personal and/or community protection. In that context, the efficacy of a mixture of a repellent (N,N-diethyl toluamide [DEET]) and a non-pyrethroid insecticide (propoxur) was investigated under laboratory conditions against both pyrethroid-susceptible and pyrethroid-resistant mosquitoes with the knockdown resistance (*kdr*) mutation. The results showed that a combination of propoxur and DEET induced a knockdown effect and mortality as high as deltamethrin (a standard pyrethroid) against the susceptible strain, and significantly higher efficacy against the pyrethroid-resistant strain. This could be explained mainly by the existence of a strong synergistic interaction between DEET and propoxur in mosquitoes. This study constitutes a first step towards an alternative strategy for improving mosquito control in areas with pyrethroid resistance.

### INTRODUCTION

Pyrethroid insecticides represent important weapons against pests of both economic and medical importance. They share many properties with dichloro-diphenyl-trichloroethane (DDT), including a knock down and killing effect, resulting from action against the sodium channels of the peripheral and central nervous systems.<sup>1</sup> These products show remarkably high efficacy against insects but relatively low mammalian toxicity and low persistence in the environment.<sup>2</sup> Since the 1980s, pyrethroids have been widely used as residual sprays on house walls or on mosquito nets to control insects in the domestic environment.<sup>3</sup> Among these anti-vector measures, pyrethroid-treated nets have emerged in recent years as the most promising tool for reducing malaria mortality and morbidity, especially in children less than five years of age in disease-endemic areas in Africa.<sup>4</sup> Insecticide-treated materials (ITMs), which include plastic sheeting, curtains, hammocks, textiles, combat uniforms, or lids of water tanks, have increased importance in personal and community protection against pests and vectors that transmit malaria, typhus, or dengue.<sup>5</sup>

Unfortunately, the emergence of pyrethroid resistance in most mosquito species of public health importance represents a threat for sustainable vector control programs implemented in the tropics. The difficulties come from the fact that resistance to any pyrethroid generally confers cross-resistance to all others, thus limiting the number of effective alternatives suitable for vector control. The knockdown resistance (*kdr*) gene, which confers cross-resistance to DDT and pyrethroids, is now widely prevalent in mosquitoes of public health importance.<sup>6-9</sup> In *Anopheles gambiae* and *Culex quinquefasciatus*, the *kdr* mutation is conferred by a single amino acid change (one or both of the two known sites) in the axonal sodium channel (insecticide-binding site), whereas knockdown resistance emerged from four amino acid substitutions in *Aedes aegypti*.<sup>9,10</sup>

The impact of the *kdr* mutation on the efficacy of ITMs has been the subject of numerous studies in Africa the past decade.<sup>11-13</sup> It has been generally observed that the *kdr* mutation was not sufficient to render pyrethroid-treated nets ineffective, which would result in a relatively high efficacy of

impregnated bed nets in killing resistant mosquitoes, but not repelling them.<sup>14,15</sup> Such a finding was explained by the fact that resistant mosquitoes, which were less irritated by the insecticide, remained longer on the nets before finally receiving sufficient lethal doses by tarsal contact.<sup>16</sup> This low irritancy may represent a serious risk against personal protection. A recent experimental hut study carried out in Benin has shown that the proportion of blood-fed females exposed to permethrin-impregnated nets was significantly higher in resistant (R) mosquitoes (both in heterozygous [RS] and homozygous [RR] individuals) than in susceptible (S) ones.<sup>13</sup> Such findings, which need be confirmed with different insecticides and impregnated substrates, already strengthen the need for alternative chemicals and/or vector control strategies to maintain an effective barrier against pyrethroid-resistant mosquitoes. This is even more relevant for insecticide-treated fabrics or clothing that should maintain a fast-acting effect against resistant insects.

Since the number of new insecticides is drastically dwindling, an alternative strategy to maintain the global effectiveness of ITMs in areas of pyrethroid resistance may be the replacement of pyrethroids by other insecticides such as carbamates or organophosphates.<sup>17</sup> Although carbamate- or organophosphate-impregnated materials have shown efficacy against pyrethroid-resistant mosquitoes, their low excitorepelleny allows mosquitoes to remain a sufficient time on the impregnated surface to take a blood meal.<sup>11,18-20</sup> Such findings may negate their use in textile or fabric impregnations.

To overcome such limitations for personal protection, we propose an alternative concept to maintain the effectiveness of impregnated materials. This consists of associating a synthetic repellent with a non-pyrethroid insecticide to mimic similar or higher features of pyrethroids, especially irritancy, against pyrethroid-resistant mosquitoes. In this study, DEET, which is a classic synthetic repellent used since World War II for personal protection, was combined with propoxur, a carbamate insecticide, which has high insecticidal activity but low irritant properties against insects.<sup>21,22</sup> The objectives of this study were to compare the intrinsic efficacy of this non-pyrethroid DEET-propoxur mixture with a reference pyrethroid insecticide (deltamethrin), and to search for synergistic

interactions between these two compounds. Susceptible and *kdr*-resistant strains of *Ae. aegypti*, an important vector for arboviruses, were used for this study.

## MATERIALS AND METHODS

**Mosquitoes.** Two laboratory strains of *Ae. aegypti* were used in this study. The susceptible Bora strain originated in French Polynesia and has no detectable insecticide resistance mechanism. The pyrethroid-resistant strain LHP originated in Vietnam and was already strongly resistant to permethrin when it was collected in the field. This strain has been maintained under constant permethrin selection at each generation and is now homozygous for the *kdr* gene (mutation L75W).<sup>2</sup> The resistant and susceptible strains were evaluated every three months for resistance status and the R genotype.

**Insecticides and repellent.** Bioassays were made with technical grade propoxur, DEET, and deltamethrin, the latter of which served as a reference for pyrethroids. The active ingredient of deltamethrin ((S)-alpha-cyano-3-phenoxybenzyl(1R,3R)-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropanecarboxylate) had a purity of 91.5% and contained at least 98% of the cis isomer. Propoxur (2-isopropoxyphenyl methylcarbamate) had a purity of 98.4%. DEET had a purity of 97% and contained a minimum of 95% of the meta isomer, the most effective molecule of DEET.

**Substrates and treatment.** Tarsal contact tests were conducted using filter paper treated with the technical grade of each insecticide and repellent. Filter papers were treated following a World Health Organization (WHO) protocol using acetone solutions of insecticide and silicone oil as the carrier.<sup>23</sup> The impregnation was done by dripping evenly onto the paper 2 mL of technical grade substance dissolved in acetone and silicone oil. The paper was dried for 12 hours before the test.

**Tarsal contact with treated filter paper.** The knockdown effect and mortality resulting from tarsal contact with treated filter paper were measured using WHO test kits against adult mosquitoes.<sup>23</sup> Concentrations were expressed in weight per weight percentage of active ingredient in silicone oil. Batches of 25 non-blood-fed female mosquitoes (2–5 days old) were introduced into holding tubes and maintained for 60 minutes at 27 ± 2°C at a relative humidity of 80 ± 10%. They were then transferred into exposure tubes and placed vertically for 60 minutes under subdued light. Since pyrethroids are fast-acting insecticides, the number of knocked-down mosquitoes at the bottom of the tubes was recorded every 10 minutes. Mortality was recorded 24 hours after exposure and corrected by the formula of Abbott<sup>24</sup> if necessary. Data were analyzed by the log-probit method of Finney<sup>25</sup> using Probit software.<sup>26</sup> Times after which 50% and 95% of mosquitoes were knocked down (KDT<sub>50</sub> and KDT<sub>95</sub>, respectively) and their 95% confidence intervals were estimated with Probit software. Each solution was tested four times and each test was repeated three times with different insect batches to take into account inter-test variability.

**Irritability tests.** Non-blood-fed female mosquitoes (2–5 days old) were individually introduced into plastic cones fitted with treated filter paper. After exposure 60 seconds, the time elapsed between the first landing and the next take off of the mosquito was recorded as the time for first take off.<sup>27</sup> Mosquitoes that did not take off at least once during a period

of 256 seconds were discarded. For each test, 50 mosquitoes were tested individually. A simple program using the internal clock of a laptop computer has been developed in our laboratory in France to conduct this test and analyze the data. Mosquitoes were grouped by classes of first take off time and cumulative frequencies were used to calculate the time for which 50% and 95% of the mosquitoes take off (FT<sub>50</sub> and FT<sub>95</sub>, respectively) using Probit software. Fairly constant subdued lighting and air temperature (28 ± 2°C) were maintained during the test according to Hodjati and Curtis.<sup>28</sup>

**Experimental design.** Lethal concentrations of propoxur that induced 30% mortality (LC<sub>30</sub>) were first determined for each strain of *Ae. aegypti* to allow better detection of synergistic interactions with DEET. The maximum irritant concentration of DEET was then determined on the susceptible strain. Therefore, the efficacy of DEET-propoxur mixtures, in terms of mortality, knockdown effect and irritancy, was compared with deltamethrin at the LC<sub>100</sub> (chosen as a pyrethroid reference concentration). To detect any synergism between DEET and propoxur, we compared the results observed with the DEET-propoxur mixture with those theoretically expected in the absence of any interaction (uncorrelated joint action) between the two compounds.<sup>29</sup> The expected mortality was calculated by multiplying the survival rates of each compound tested separately and subtracting the result from 100%.

In the same way, the expected KDT and FT for the mixture was calculated by multiplying the percentage of mosquitoes that were not knocked down (air-landed mosquitoes) at each time and subtracting the results from 100%. Synergism occurred when the observed results were significantly higher than the expected one. Conversely, when the observed results were significantly lower than the expected one, there was antagonism.

**Statistical analysis.** Mortality rates for DEET and propoxur alone and combined were compared with Yates' corrected chi-square test at 0.05% level of significance. The differences between two KDT<sub>50-95</sub> and two FT<sub>50-95</sub> values were considered significant if their 95% confidence intervals did not overlap.

## RESULTS

**Preliminary data.** The maximum irritant concentration of 1% DEET induced no mortality and no knockdown effect (Tables 1 and 2). The LC<sub>50</sub>s of propoxur were 0.02% and 0.01% for the Bora and LHP strains, respectively. At this concentration, propoxur induced no knockdown effect and only low irritancy against both mosquito strains (Tables 2 and 3). The LC<sub>100</sub> of deltamethrin was estimated to be 0.014% for the Bora strain. The DEET-propoxur mixtures tested on mosquitoes were 0.02% propoxur plus 1% DEET for the Bora strain and 0.01% propoxur plus 1% DEET for the LHP strain. All results (mortality, knockdown effect, and irritancy) obtained with each insecticide and repellent, alone or in mixture, are summarized in Tables 1, 2 and 3.

**Comparative efficacy between deltamethrin and the DEET-propoxur mixture.** The mortality rate of the Bora strain (100%) when tested with deltamethrin did not differ significantly from that with DEET-propoxur mixture (96%) ( $\chi^2 = 2.30$ , degrees of freedom [df] = 1,  $P = 0.13$ ) (Table 1), but the knockdown effect was significantly higher than with

TABLE 1

Mortality at 24 hours of susceptible (Bora) and kdr-resistant (LHP) *Aedes aegypti* mosquitoes exposed for one hour to papers impregnated with deltamethrin, propoxur, and DEET, separate or combined\*

		Insecticidal effect			$\chi^2$ (P)
		Dose, %	No	% mortality	
<i>Ae. aegypti</i> (Bora)	Control	—	300	No effect	—
	Propoxur LC <sub>50</sub>	0.02	300	34.0	—
	DEET	1	300	No effect	—
	Mixture (observed)	0.02 + 1	300	96.0	81.78†
	Mixture (expected)	—	—	34.0	( $< 0.0001$ )
	Deltamethrin LC <sub>100</sub>	0.014	300	100.0	2.30‡ (0.1297)
<i>Ae. aegypti</i> (LHP)	Control	—	300	No effect	—
	Propoxur LC <sub>50</sub>	0.01	275	34.5	—
	DEET	1	300	No effect	—
	Mixture (observed)	0.01 + 1	300	94.6	76.51†
	Mixture (expected)	—	—	34.5	( $< 0.0001$ )
	Deltamethrin LC <sub>100</sub>	0.014	300	9.3	144.73‡ ( $< 0.00001$ )

\* Kdr = knock down resistance; DEET = N, N-diethyl-m-toluamide; LC = lethal concentration.

†  $\chi^2$  square and its probability between expected and observed mortalities.

‡  $\chi^2$  square and its probability between deltamethrin and mixture-induced mortalities.

the DEET-propoxur mixture (both at the KDT<sub>50</sub> and KDT<sub>95</sub> levels) (Table 2). Irritancy of deltamethrin was greater than that of the DEET-propoxur mixture at the FT<sub>50</sub> level, but not significantly different at the FT<sub>95</sub> level (Table 3).

The mortality rate of the LHP strain when tested with deltamethrin was fairly low (9%), but remained high (94%) with the DEET-propoxur mixture ( $\chi^2 = 144.73$ , df = 1,  $P < 0.0001$ ) (Table 1). In addition, the knockdown effect of deltamethrin was not observed in the LHP strain, but was high in the Bora strain (Table 2). The irritant properties of deltamethrin and the DEET-propoxur mixture did not differ significantly from each other at both the FT<sub>50</sub> and FT<sub>95</sub> levels (confidence intervals overlapped) (Table 3).

**Interaction between DEET and propoxur.** The DEET-propoxur mixture showed a significantly higher mortality rate (96%) in the Bora strain than expected (34%) when testing the hypothesis of an uncorrelated joint action of the two compounds ( $\chi^2 = 81.78$ ; df = 1,  $P < 0.0001$ ) (Table 1). Such results indicate a strong synergism between propoxur and DEET. Moreover, the existence of a knockdown effect with

the DEET-propoxur mixture also provided evidence for a striking synergism between these two compounds since DEET and propoxur tested separately did not induce any knockdown effect (Table 2). However, irritancy of the DEET-propoxur mixture was not significantly different from that theoretically expected, indicating an additive effect for this parameter (Table 3).

A synergistic interaction was also observed between DEET and propoxur in the LHP strain for both the mortality rate (94.5% versus 34.5%;  $\chi^2 = 76.51$ , df = 1,  $P < 0.0001$ ) (Table 1) and the knockdown effect (KDT<sub>50</sub> = 41.5 minutes) (Table 2). Conversely, irritancy of the DEET-propoxur mixture was significantly lower than that theoretically expected, indicating an antagonistic interaction between these two compounds (confidence intervals did not overlap) (Table 3).

## DISCUSSION

The combination of propoxur (at the LC<sub>50</sub>) and DEET (at a sub-lethal dose) showed irritant properties as high as del-

TABLE 2

Knock-down times (KDT<sub>50</sub> and KDT<sub>95</sub>) of susceptible (Bora) and kdr-resistant (LHP) *Aedes aegypti* mosquitoes exposed for one hour to papers impregnated with deltamethrin, propoxur, and DEET, separate or combined\*

		Knock-down effect				
		Dose, %	No	KDT <sub>50</sub> (min)	95% CI	95% CI
<i>Ae. aegypti</i> (Bora)	Control	—	300	No effect	—	—
	Propoxur LC <sub>50</sub>	0.02	300	No effect	—	—
	DEET	1	300	No effect	—	—
	Mixture (observed)	0.02 + 1	300	36.6	35.7–37.4	54.8
	Mixture (expected)	—	—	—	—	—
	Deltamethrin LC <sub>100</sub>	0.014	300	23.8	21.6–26.2	38.3
<i>Ae. aegypti</i> (LHP)	Control	—	300	No effect	—	—
	Propoxur LC <sub>50</sub>	0.01	300	No effect	—	—
	DEET	1	300	No effect	—	—
	Mixture (observed)	0.01 + 1	300	41.5	40.6–42.4	60.1
	Mixture (expected)	—	—	—	—	—
	Deltamethrin LC <sub>100</sub>	0.014	300	No effect	—	—

\* KDT<sub>50</sub> = 50% knock-down time, KDT<sub>95</sub> = 95% knock-down time, DEET = N, N-diethyl-m-toluamide, CI = confidence interval, LC = lethal concentration.

TABLE 3

Time of first take-off (FT<sub>50</sub> and FT<sub>95</sub>) of susceptible (Bora) and kdr-resistant (LHP) *Aedes aegypti* mosquitoes exposed to papers impregnated with deltamethrin, propoxur, and DEET, separate or combined.\*

		Irritant effect					
		Dose, %	No.	FT <sub>50</sub> (sec)	95% CI	FT <sub>95</sub> (sec)	95% CI
<i>Ae. aegypti</i> (Bora)	Control	–	163	251	188.8–363.9	6,256.1	3,122.2–16,269.7
	Propoxur LC <sub>50</sub>	0.02	150	133.9	108.8–172.3	2,508.1	1,486.7–4,993.3
	DEET	1	150	24.2	21.9–26.8	128.2	107.6–157.4
	Mixture (observed)	0.02 + 1	150	21.5	18.7–24.6	88.9	69.7–114.7
	Mixture (expected)	–	–	19.2	17.0–21.7	96.4	78.7–123.3
<i>A. aegypti</i> (LHP)	Deltamethrin LC <sub>100</sub>	0.014	150	15.4	13.9–17.1	86.9	72.9–106.8
	Control	–	150	81.2	63.8–104.0	739.3	379.0–1,501.8
	Propoxur LC <sub>50</sub>	0.01	153	62.5	54.0–73.6	856.9	607.3–1,308.0
	DEET	1	150	23.6	19.3–28.9	172.1	116.1–257.8
	Mixture (observed)	0.01 + 1	152	23.6	21.2–26.2	159.3	133.2–195.8
	Mixture (expected)	–	–	15.8	14.0–17.9	101.6	81.1–133.2
	Deltamethrin LC <sub>100</sub>	0.014	152	24.1	21.5–27.0	183.2	148.0–236.1

\* FT<sub>50</sub> = 50% take-off time; FT<sub>95</sub> = 95% take-off time; DEET = N,N-diethyltoluamide; CI = confidence interval; LC = lethal concentration.

tamethrin (at the LC<sub>100</sub>) against both Bora and LHP mosquito strains, although irritancy was slightly lower against LHP mosquitoes. In the LHP strain, the decrease in irritancy with deltamethrin might be due to the presence of the *kdr* mutation, although it probably results from a more complex phenomenon for the DEET-propoxur combination. It is likely that the massive knockdown effect observed with the DEET-propoxur mixture disrupted the time for first take off of mosquitoes, since knocked-down mosquitoes were unable to fly. This phenomenon probably explained the antagonistic interaction in irritancy observed between propoxur and DEET in the LHP strain.

A strong synergism was reported between an insecticide and a repellent. The level of synergy detected with this non-pyrethroid DEET-propoxur mixture was higher than those previously observed between pyrethroids and carbamates (e.g., propoxur) or organophosphates against *Anopheles* mosquitoes.<sup>30,31</sup> The most intriguing result was the manifestation of a knockdown effect induced by compounds other than pyrethroids, especially against LHP mosquitoes. Such findings are of practical importance since the knockdown effect is an essential characteristic in personal protection against mosquito bites.

The physiologic mechanisms responsible for synergistic interactions between DEET and propoxur remain unclear. The mode of action of carbamates is well known (inhibition of acetylcholinesterase), but that of DEET has not been elucidated.<sup>32</sup> Davis proposed several assumptions to explain the effect of DEET in insects<sup>33</sup>: 1) inhibition of an attraction signal; 2) inversion of attraction signal perception for an irritant message; 3) activation of a receptor system that could mediate a competing or inappropriate behavior pattern; 4) activation of a noxious odor receptor; and 5) activation of different receptors that could mediate various behavior patterns, indicating that repellents are interfering with the sensory information system.

In this study, we used filter papers without any vertebrate host. DEET acts not only by inducing a disruption of an attraction signal, but also by generating a physiologic perturbation in mosquitoes. Indeed, preliminary bioassays have shown that a DEET concentration range of 5–10% induced mortality and a knockdown effect as great as pyrethroids (Pennetier C, unpublished data). In addition, electrophysi-

ologic tests with dorsal unpaired median neurons of American cockroach (*Periplaneta americana*) showed that DEET induced a strong neurotoxic effect (Lapied B, unpublished data). As previously observed by Corbel and others<sup>34</sup> with insecticide combinations, synergism between DEET and propoxur may be the result of a general physiologic disruption involving different target sites in the central nervous system. Further investigations are now in progress to determine precisely the mode of action of DEET alone and in combination with other compounds on insect physiology.

Another possible explanation for the observed synergism is detoxification by enzymes in insects. One component of the DEET-propoxur mixture may interfere with the detoxification of the other, thereby increasing the toxicity of the two compounds.<sup>35,36</sup> For example, synergism between organophosphates and pyrethroids was caused by sequestration of organophosphates by esterases, which prevented the degradation of pyrethroids.<sup>37</sup> Although DEET does not share ester bonds, other enzymes such as oxidases have been shown to be involved in its detoxification and could therefore play a role in synergism.<sup>38–40</sup>

In conclusion, a DEET-propoxur mixture may be a new promising tool for vector control because pyrethroid resistance is now widely prevalent in mosquitoes worldwide, especially in Africa. The control of *Ae. aegypti*, which is based mainly on pyrethroid sprays or impregnated materials, is being threatened by pyrethroid resistance. A combination of DEET and propoxur (or others carbamates) may improve personal protection against kdr-resistant mosquitoes and contribute to a better management of pyrethroid resistance. Another use for such a mixture stems from the fact that the *Ace.1<sup>R</sup>* mutation (G119S), which confers cross-resistance to organophosphates and carbamates, has never been observed in *Ae. aegypti*, and is unlikely to appear since it requires a double mutation.<sup>41,42</sup> In contrast to *Ae. aegypti*, the *Ace.1<sup>R</sup>* mutation has been found in *An. gambiae*, the main malaria vector in Africa and in *Cx. quinquefasciatus*, the main urban mosquito in tropical areas.<sup>43</sup> It will be interesting to investigate the impact of the *Ace.1<sup>R</sup>* gene on the efficacy of this DEET-propoxur mixture. Since DEET is a volatile compound, there is an urgent need to search for an adequate formulation that could extend the residual effect of this combination in impregnated materials. Recent investigations in

the laboratory have shown that efficacy of a DEET-based formulation (Insect Ecran®; Osler, Paris, France) persisted for at least 45 days on netting against pyrethroid-resistant *Cx. quinquefasciatus* (N'Gueassan R, unpublished data). These findings constitute a first step towards an alternative strategy of combating vectors of human diseases.

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**Authors' addresses:** Cédric Penetier and Vincent Corbel, Laboratoire de Lutte contre les Insectes Nuisibles, Institut de Recherche pour le Développement, 911 Avenue Agostino, BP 64501, 34394 Montpellier cedex 5, France. Telephone: 33-467-04-19-24, Fax: 33-467-04-20-44. E-mails: cedric.penetier@ird.fr and corbel@mpl.ird.fr. Jean-Marc Hougaard, Centre Institut de Recherche pour le Développement du Bénin, 01 BP 4414 RP, Cotonou, Bénin, Telephone: 229-30-03-54, Fax: 229-30-88-60. E-mail: hougaard@ird.fr.

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